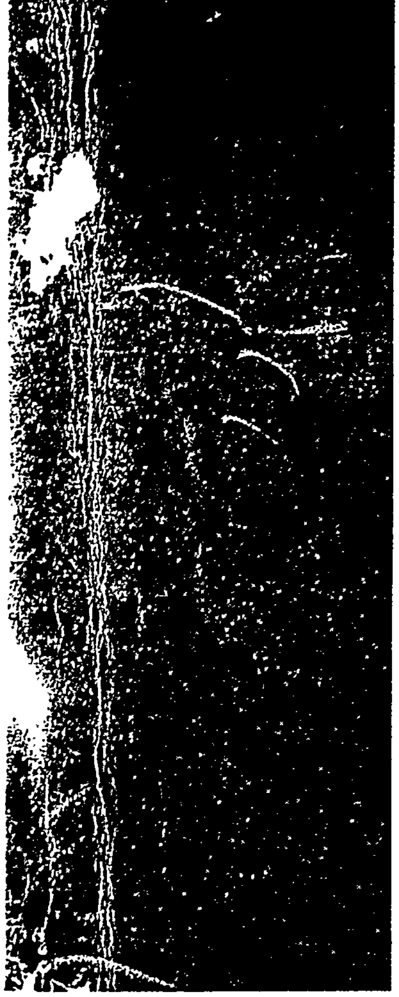

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# Preliminary Investigation of $^{90}$SR in White Oak Creek Between Monitoring Stations 2 and 3, Oak Ridge National Laboratory


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ENVIRONMENTAL SCIENCES DIVISION
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# PRELIMINARY INVESTIGATION OF $^{90}SR$ IN WHITE OAK CREEK BETWEEN MONITORING STATIONS 2 AND 3, OAK RIDGE NATIONAL LABORATORY

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# ABSTRACT

STUEBER, A. M., D. E. EDGAR, A. F. MCFADDEN, and T. G. SCOTT. 1978. Preliminary investigation of $^{90}Sr$ in White Oak Creek between monitoring stations 2 and 3, Oak Ridge National Laboratory. ORNL/TM-6510. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 90 pp.

A comprehensive water-sampling program has been carried out in the vicinity of Solid Waste Disposal Area (SWDA) 4 and in the reach of White Oak Creek between monitoring stations 2 and 3 in order to investigate the substantial increase in $^{90}Sr$ discharge recorded at monitoring station 3 in recent years. On the basis of $^{90}Sr$ concentrations in ground-water samples from wells around the perimeter of SWDA 4 and in surface-water samples from the stream to the south of this disposal area there seems to be no present increase in $^{90}Sr$ discharge from this source. Although SWDA 4 continues to be a major source of $^{90}Sr$ input to this reach of White Oak Creek, it is clear that there are two additional sources, the Sewage Treatment Plant and Waste Ponds 3539 and 3540, which have been of comparable importance. Therefore it is incorrect to assign the increment in White Oak Creek $^{90}Sr$ discharge between monitoring stations 2 and 3 entirely to discharge from SWDA 4. It is possible that the relatively high $^{90}Sr$ discharges recorded at monitoring station 3 in recent years were due to elevated $^{90}Sr$ activity levels in the effluent from either the Waste Ponds or the Sewage Treatment Plant, or both. By eliminating the contamination in the effluents from these two sources, the $^{90}Sr$ discharge at monitoring station 3 could be approximately halved.

The $^{90}Sr$ discharge from the northwest tributary to White Oak Creek is relatively small but nevertheless significant. Evidence is presented to warrant a thorough study of $^{90}Sr$ release from SWDA 3. At present the discharge of $^{90}Sr$ from contaminated floodplain areas adjacent to White Oak Creek does not seem to present a serious problem. Direct surface runoff after storm events is not a significant source of $^{90}Sr$ discharge to the study reach of White Oak Creek; the transport of $^{90}Sr$ by suspended matter in the creek was apparently of minor importance during this investigation.

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# INTRODUCTION

Investigations of the solid waste disposal areas (SWDAs) at Oak Ridge National Laboratory (ORNL) are concerned primarily with determining the contributions of radionuclides from buried waste to the Clinch River, and with implementing corrective measures. The radionuclide of greatest concern is $^{90}Sr$ because of its concentration in White Oak Creek at monitoring station 5 (White Oak Dam), the point of release to the Clinch River (Fig. 1). The maximum acceptable concentration of a particular radionuclide permitted in discharged effluent is referred to as the Maximum Permissible Concentration (MPC). During the four-year period from 1974 through 1977, the average annual concentration of $^{90}Sr$ at White Oak Dam has ranged from 80 to 195% of MPC. However, the $^{90}Sr$ concentration in Clinch River water downstream from White Oak Creek outfall is far below the MPC because of dilution in the White Oak Creek estuary below White Oak Dam and in the river itself.

The contributions of $^{90}Sr$ from various areas within White Oak Creek drainage basin to the effluent discharged over White Oak Dam can be evaluated by considering stream-monitoring data collected at five stations (Table 1; Fig. 1). On a yearly basis, the total strontium passing monitoring station 3 is comparable with or even greater than that which is discharged over White Oak Dam (monitoring station 5). Further inspection of the data in Table 1 reveals that the $^{90}Sr$ passing monitoring station 2 is only a small percent of that discharged at monitoring station 3. Therefore, it seems that the bulk of the $^{90}Sr$ released to the Clinch River is acquired by White Oak Creek in its reach between monitoring stations 2 and 3.

Monitoring station 1 (Fig. 1) records the $^{90}Sr$ discharged from the Process Waste Treatment Plant to White Oak Creek. Prior to April 1976, when a new Process Waste Treatment Plant went into operation, the $^{90}Sr$ discharged from this facility represented a large proportion of the $^{90}Sr$ passing monitoring station 3 (Table 1). The $^{90}Sr$ entering White Oak Creek between monitoring stations 2 and 3 from unmonitored sources is obtained by subtracting the sum of the readings at stations

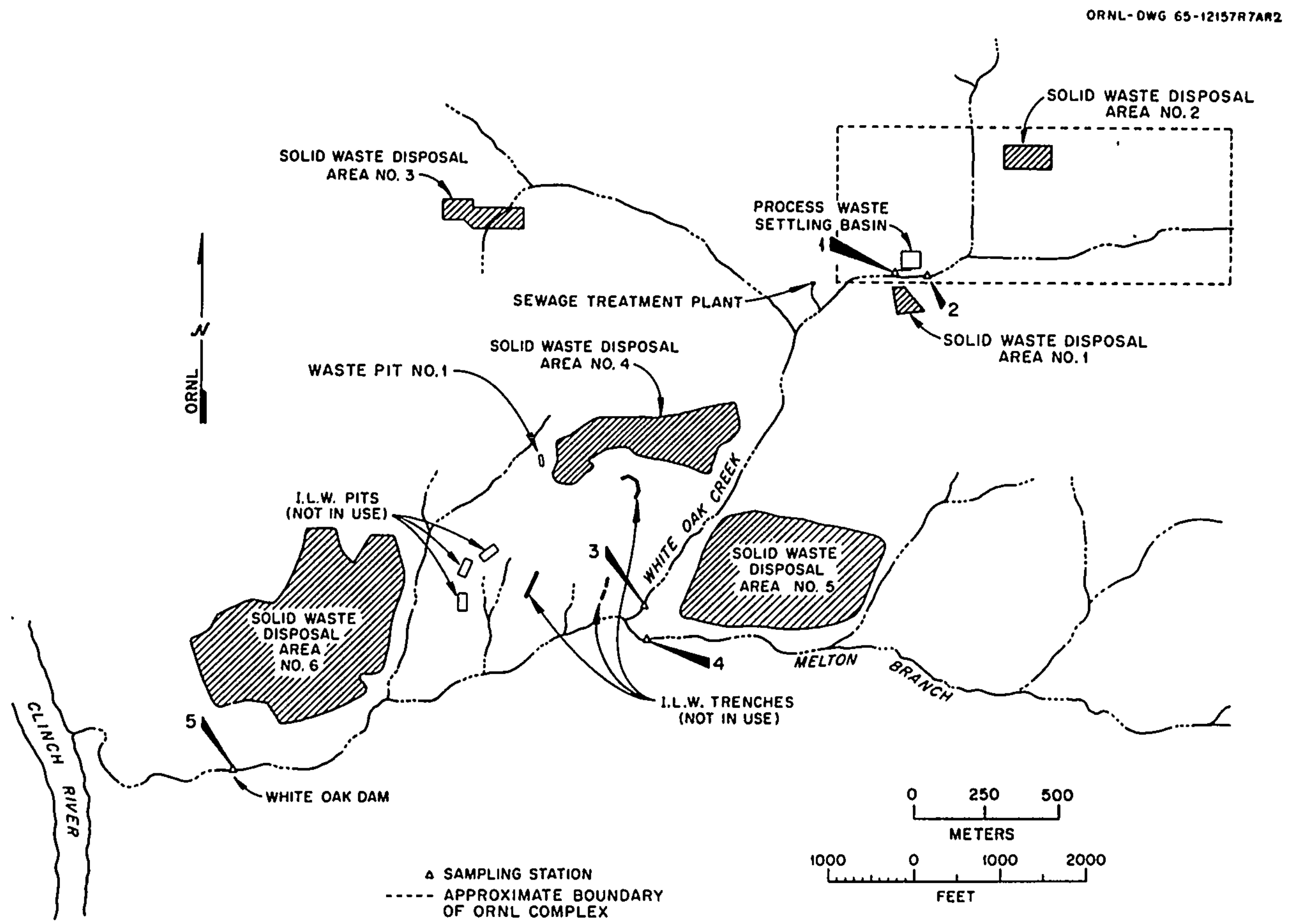


Fig. 1. Approximate locations of waste disposal areas and sampling stations at ORNL.

Table 1. Total Sr (Ci) discharged at ORNL monitoring stations (see Fig. 1 for locations). Data collected from monthly reports of Radioactive Waste Disposal Operations and Effluent Monitoring.

| Calender year | Monitoring stations | | | | | 3-(1+2) | $\left[\frac{3-(1+2)}{5}\right] \times 100$ |
|---|---|---|---|---|---|---|---|
| | 5 | 4 | 3 | 2 | 1 | | |
| 1964 | 7.28 | 0.69 | 6.47 | 0.19 | 2.99 | 3.29 | 45.2 |
| 1965 | 4.17 | 0.31 | 5.13 | 0.25 | 1.48 | 3.40 | 81.5 |
| 1966 | 3.86 | 0.47 | 5.45 | 0.14 | 3.31 | 2.00 | 51.8 |
| 1967 | 5.82 | 0.95 | 6.87 | 0.13 | 4.06 | 2.68 | 46.1 |
| 1968 | 3.29 | 2.80 | 4.05 | 0.13 | 2.19 | 1.73 | 52.6 |
| 1969 | 3.33 | 0.92 | 3.37 | 0.39 | 1.69 | 1.29 | 38.7 |
| 1970 | 4.17 | 0.74 | 3.68 | 0.38 | 1.95 | 1.35 | 32.4 |
| 1971 | 3.40 | 0.61 | 3.45 | 0.19 | 1.54 | 1.73 | 50.9 |
| 1972 | 6.00 | 0.91 | 6.18 | 0.29 | 3.71 | 2.18 | 36.3 |
| 1973 | 6.33 | 1.30 | 5.27 | 0.70 | 2.58 | 1.99 | 31.4 |
| 1974 | 6.08 | 1.30 | 8.93 | 0.78 | 2.80 | 5.35 | 88.0 |
| 1975 | 7.15 | 2.14 | 7.13 | 0.24 | 3.29 | 3.60 | 50.4 |
| 1976 | 4.51 | 0.67 | 6.08 | 0.43 | 1.38 | 4.27 | 94.7 |
| 1977 | 2.71 | 0.49 | 2.87 | 0.22 | 0.09 | 2.56 | 94.5 |

1 and 2 from the discharge at station 3 (Table 1, column 7). These contributions are expressed as a percent of the $^{90}Sr$ passing White Oak Dam on a yearly basis in the last column in Table 1.

The installation of the new Process Waste Treatment Plant has reduced $^{90}Sr$ contributions from this source to White Oak Creek to an almost insignificant level, as shown by the 1977 data (Table 1). The unmonitored $^{90}Sr$ sources which contribute to the creek between stations 2 and 3 are now of paramount importance in relation to the release of $^{90}Sr$ to the Clinch River at monitoring station 5. The purpose of this report is to present the results of investigations conducted to identify and evaluate these sources.

## STRONTIUM-90 CONTRIBUTIONS TO WHITE OAK CREEK FROM SOLID WASTE DISPOSAL AREAS

The significance of the yearly $^{90}Sr$ discharge at monitoring station 3 was pointed out by Duguid (1975), who evaluated the importance of the solid waste disposal areas as contributors to this discharge (Fig. 1). On the basis of very low $^{90}Sr$ concentrations in water samples from wells, seeps, and intermittent streams adjacent to SWDAs 1, 3, and 5, Duguid concluded that these disposal areas are not important sources of the $^{90}Sr$ in White Oak Creek at monitoring station 3. However, significantly higher $^{90}Sr$ concentrations in samples from wells and seeps adjacent to SWDA 4 suggested that this disposal area is a major source of $^{90}Sr$ in White Oak Creek.

The discharge of $^{90}Sr$ from SWDA 4 to White Oak Creek cannot be measured directly. It has been estimated in the past through the use of a network of wells and surface-sampling sites established adjacent to the disposal area on the floodplain of White Oak Creek (Duguid 1975). These locations have been sampled approximately three times a year; the average concentration of $^{90}Sr$ in water entering White Oak Creek from SWDA 4 has in turn been obtained by multiplying the average $^{90}Sr$ concentration by a flux of infiltrated water that has been estimated according to a technique based upon the difference between annual precipitation and evapotranspiration values for Walker Branch Watershed (Duguid 1975).

The apparent annual $^{90}Sr$ discharge from SWDA 4 can also be obtained from stream-monitoring data along White Oak Creek by subtracting the $^{90}Sr$ discharged from plant operations (stations 1 and 2) from the $^{90}Sr$ discharge at monitoring station 3 (Fig. 1). Values obtained in this way for water years 1963 through 1977 are presented in Table 2. A plot of these data (Fig. 2, after Duguid 1976) indicates that, for water years 1963 through 1973, the $^{90}Sr$ discharge per cm of precipitation from SWDA 4 shows a steady decline. More recent data, however, show a reversal of this trend.

Calculated estimates of the $^{90}Sr$ discharge from SWDA 4 for the past five water years, according to the method of Duguid (1975), are compared with $^{90}Sr$ discharges based on stream-monitoring data in Table 3. With the exception of water year 1973, stream monitoring data indicate considerably greater $^{90}Sr$ discharge from SWDA 4 than that which is estimated by calculation. The discrepancies suggest any one or more of the following: (1) a malfunction of monitoring station 3; (2) inadequacies in the technique used to calculate $^{90}Sr$ discharge from SWDA 4; and (3) a new source or sources of $^{90}Sr$ input to White Oak Creek above monitoring station 3.

Duguid (1976) suggested that the recent high $^{90}Sr$ discharges from SWDA 4 that are indicated by stream-monitoring data could be due to a malfunction in monitoring station 3, which occurred post-1974 but was not discovered until 1976. While such a malfunction could have affected the apparent $^{90}Sr$ discharge for water years 1975 and 1976, the discrepancies between calculated and stream-monitored discharges are not confined to these water years. Other possible reasons for the recent apparently higher discharges should be investigated.

The technique used to calculate the annual $^{90}Sr$ discharge from SWDA 4 should be regarded as yielding only a crude estimate (Duguid 1975). The flux of infiltrated water is obtained by neglecting the surface runoff component of precipitation; however, any error introduced

Table 2. Discharge of $^{90}Sr$ from SWDA 4 and precipitation data for water years 1963 through 1977

| Water year[a] | Precipitation (cm) | Total $^{90}Sr$ discharge (Ci) | Discharge of $^{90}Sr$ (mCi/cm) |
|---|---|---|---|
| 1963 | 141 | 4.82 | 34.2 |
| 1964 | 107 | 2.98 | 27.9 |
| 1965 | 132 | 3.10 | 23.5 |
| 1966 | 104 | 2.52 | 24.2 |
| 1967 | 154 | 2.72 | 17.7 |
| 1968 | 114 | 2.04 | 17.9 |
| 1969 | 102 | 2.08 | 20.4 |
| 1970 | 122 | 1.60 | 13.1 |
| 1971 | 123 | 1.18 | 9.6 |
| 1972 | 120 | 2.36 | 19.7 |
| 1973 | 181 | 1.58 | 8.7 |
| 1974 | 175 | 5.22 | 29.8 |
| 1975 | 147 | 3.22 | 21.9 |
| 1976 | 124 | 5.12 | 41.3 |
| 1977 | 129 | 2.27 | 17.6 |

[a]Water year is September 1 through August 31.

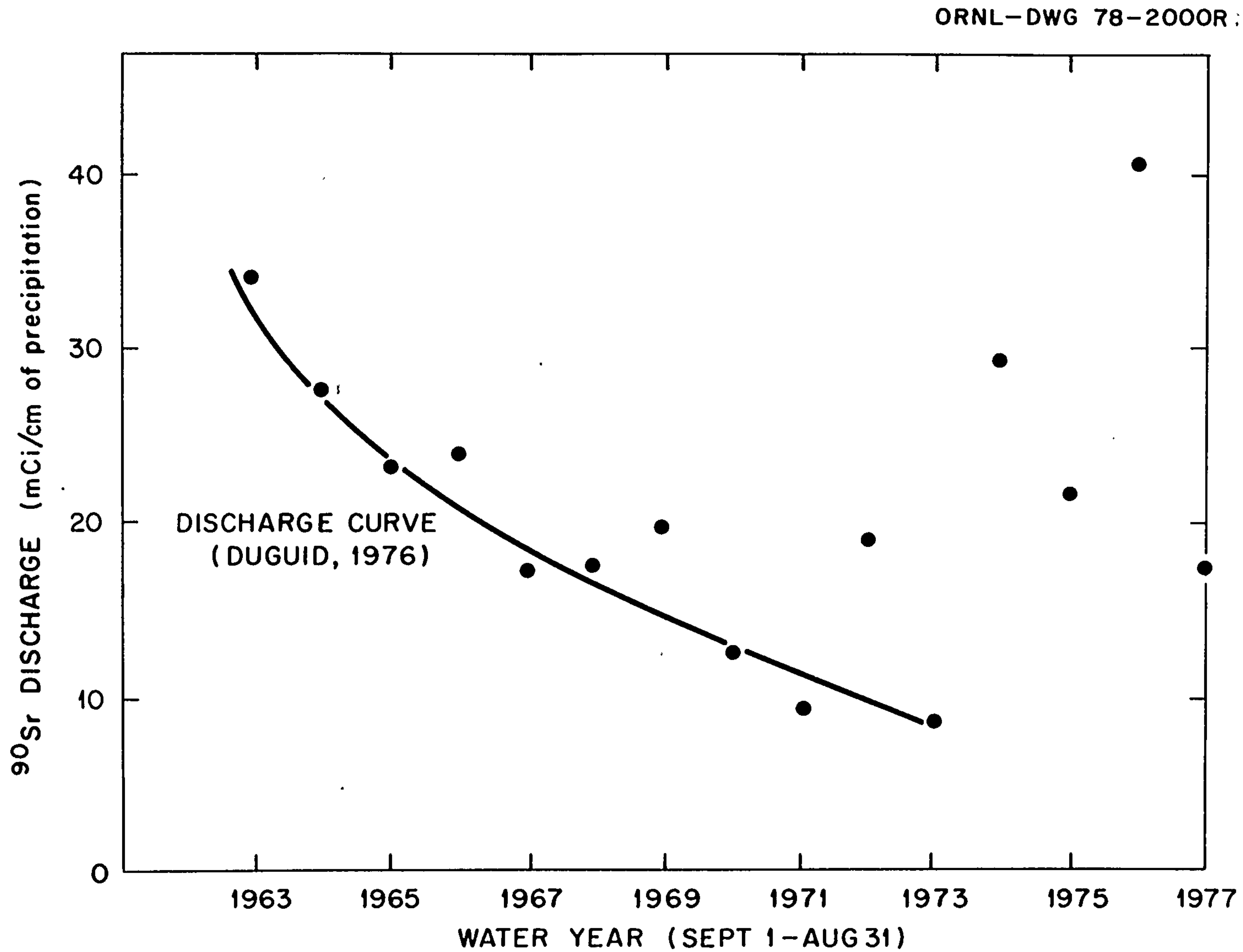


Fig. 2. Discharge of $^{90}Sr$ from SWDA 4 for water years 1963 through 1977, in millicuries per cm of precipitation, from steam-monitoring data.

Table 3. Strontium-90 discharge from SWDA 4 (Ci/year)

| Water year | Calculated | Stream monitoring |
|---|---|---|
| 1973 | 1.7 | 1.58 |
| 1974 | 1.6 | 5.22 |
| 1975 | 1.2 | 3.22 |
| 1976 | 0.65 | 5.12 |
| 1977 | 1.1 | 2.27 |

by this approximation will yield an apparent $^{90}Sr$ discharge from below the ground surface which is too high. A more significant potential source of error introduced by neglecting surface runoff lies in the possibility that $^{90}Sr$ is being leached from surficial sources and carried directly into White Oak Creek without being intercepted by the ground-water monitoring network. Furthermore, the average concentration of $^{90}Sr$ in water entering White Oak Creek from the disposal area is based upon samples from the monitoring network which are obtained only twice during the water year; the degree to which this relatively infrequent sampling represents the yearly average needs to be evaluated. In addition, the wells that comprise the monitoring network are very shallow and do not intercept any deep ground-water component that may have a different $^{90}Sr$ activity.

There is a possibility that SWDA 4 is not the only significant source of $^{90}Sr$ discharge to White Oak Creek between monitoring stations 2 and 3. Monitoring wells in the vicinity of SWDA 1 and SWDA 3 and on the west side of SWDA 5 were last tested in 1973 (Duguid 1975). Although at that time the $^{90}Sr$ activities in the water samples indicated that these potential sources were insignificant contributors to White Oak Creek, these monitoring wells should be checked again. They were sampled only one time during the reconnaissance survey; the $^{90}Sr$ activities in the ground waters may be a function of hydrologic parameters which vary with time.

Another potentially significant source of $^{90}Sr$ in White Oak Creek between monitoring stations 2 and 3 may be found in the soil on the floodplain of the creek adjacent to SWDA 4, and in the soil and sediment along the creek channel and in the floodplains above SWDA 4. There is some evidence to suggest such a source may be responsible for the abnormally high $^{90}Sr$ discharge of White Oak Creek between monitoring stations 2 and 3 during recent water years. Binford and Gissel (internal communication, 1975, Oak Ridge National Laboratory) observed a linear relationship between White Oak Creek monthly flow and apparent $^{90}Sr$ monthly contribution to White Oak Creek from SWDA 4 for the period June 1971 through March 1974. Such a relationship infers that the $^{90}Sr$ concentration in White Oak Creek near monitoring station 3 is essentially constant. Because monthly stream flow varies to some degree as a function of monthly rainfall, there must be a relatively rapid interaction between rainfall and the $^{90}Sr$ source in order to maintain the relatively constant $^{90}Sr$ concentration in the creek. This requirement seems to eliminate infiltration and movement through SWDA 4 and suggests a surficial source near White Oak Creek. Duguid (1976) reported significant $^{90}Sr$ concentrations in the soils on the floodplain adjacent to the disposal area. The soil and sediment along the creek channel and in the floodplains above the disposal area may be contaminated with $^{90}Sr$ discharged from the former Process Waste Treatment Plant. These potential surficial sources of $^{90}Sr$ need to be investigated further.

## INVESTIGATION OF INCREASED $^{90}SR$ CONTRIBUTIONS TO WHITE OAK CREEK IN THE VICINITY OF SWDA 4

The stream-monitoring data which indicate increased $^{90}Sr$ input to White Oak Creek in recent years from unmonitored sources between monitoring stations 2 and 3 seem to represent the real situation. The increase could be attributed to SWDA 4, or to new sources of $^{90}Sr$ input above monitoring station 3. As a first step in evaluating the situation, an experiment was designed to monitor $^{90}Sr$ activity in ground water from selected wells around the periphery of SWDA 4 and on the west side of SWDA 5, and to monitor $^{90}Sr$ activity in White Oak Creek immediately above and below SWDA 4.

The following wells (Fig. 3) were chosen for ground-water sampling around the perimeter of SWDA 4: 179, 183, 186, 191, 196, and 201. The stream below SWDA 4 was sampled at two locations, S214/W90 and S228/W90. Samples were obtained from White Oak Creek at stations WOC-A and WOC-B. Wells 456 and 457, along the southwest boundary of SWDA 5 (not shown in Fig. 3), were included in the sampling program. The northwest tributary (Fig. 1) was sampled at a point near its confluence

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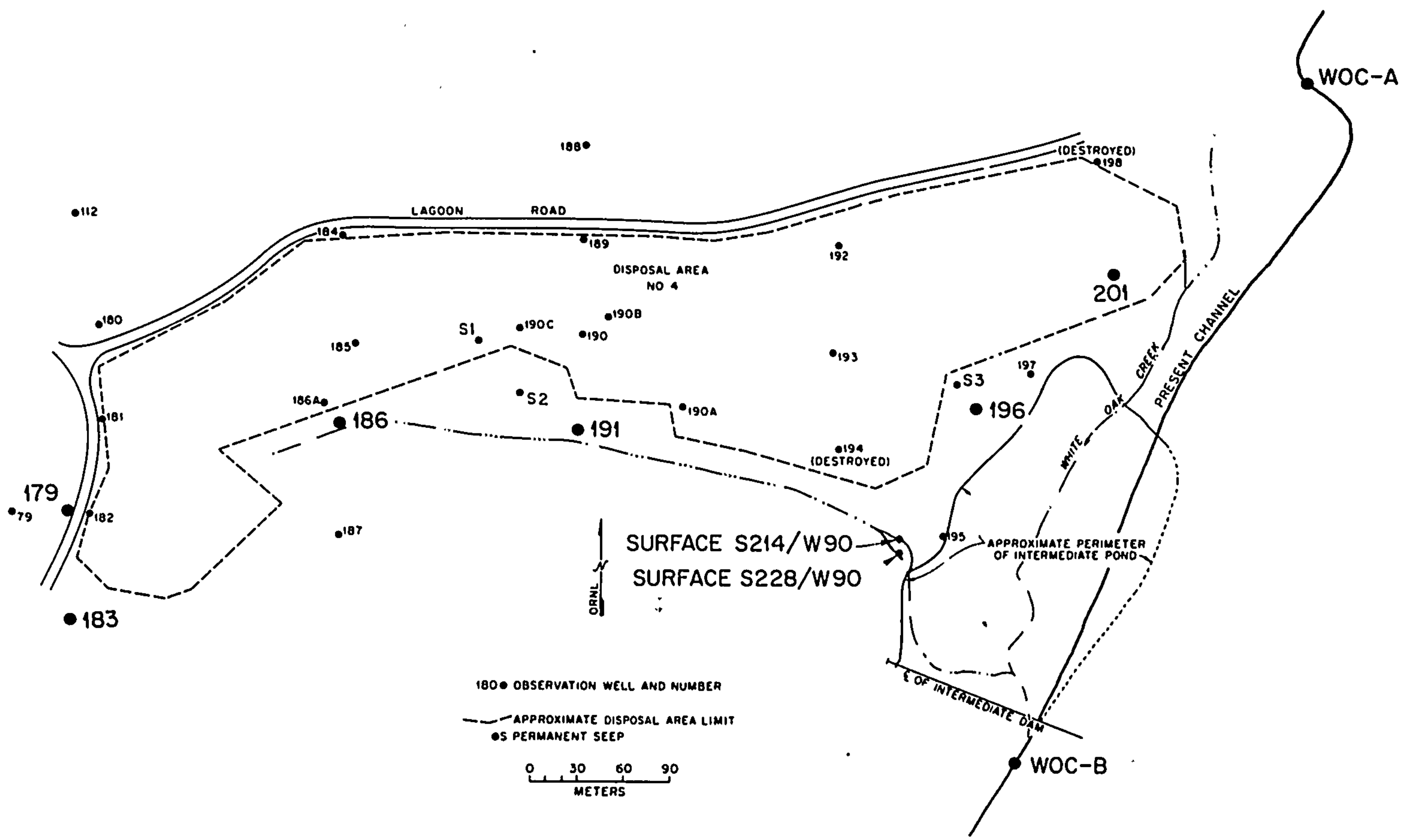


Fig. 3. Locations of surface- and ground-water sampling sites in the vicinity of SWDA 4.

with White Oak Creek, in order to assess the $^{90}Sr$ input from SWDA 3 to the creek. Samples were obtained from each of these sites three times each week during October 1977. The intensive sampling was designed to obtain representative data from each site, and to evaluate any effects of varying hydrologic conditions on the $^{90}Sr$ activity levels. Water-table elevation was measured in each well at the time each sample was taken. Daily precipitation was recorded at a location within SWDA 4. The $^{90}Sr$ concentrations in all water samples and the precipitation measurements are presented in Table 4.

Activity levels of $^{90}Sr$ considerably higher than background were detected in ground-water samples from only three wells, located on the perimeter of SWDA 4: 186, 191, and 196 (Table 4). Comparison with similar data for samples from the same wells collected at various times in the past (Table 5) reveals no increase in $^{90}Sr$ concentration in these ground waters at the present time. Indeed, the activities in wells 186 and 196 seem to be decreasing with time, although the levels may reflect somewhat the ambient hydrologic conditions when the samples were taken. The $^{90}Sr$ concentrations in water samples from the three wells did fluctuate with time during October 1977 (Table 4); the variations seem to be a function of precipitation and water-table elevation (Figs. 4, 5, and 6). Precipitation appears to have a short-term dilutive effect on $^{90}Sr$ activity in the ground water, although recovery seems to be fairly rapid.

The present analyses indicate no increase in ground-water transport of $^{90}Sr$ from SWDA 4, although only six widely spaced wells were sampled. However, Duguid (1976) came to the same conclusion on the basis of ground-water analyses from a network of closely spaced shallow wells on the floodplain east of SWDA 4 (Fig. 3). Perhaps a better indication of any changes in $^{90}Sr$ discharge from SWDA 4 with time is given by the analyses of surface water from two branches of the stream which flows along the south boundary of the disposal area (Table 4; Fig. 3). These sites have been sampled regularly since 1973 as a part of the monitoring network (Duguid 1975, 1976). The $^{90}Sr$ concentrations in the surface stream show no significant change with

Table 4. Strontium-90 concentrations (dpm/ml) in water samples collected during October 1977, and precipitation measurements. Precipitation is for period between each date.

| | 10/3 | 10/5 | 10/7 | 10/10 | 10/12 | 10/14 | 10/17 | 10/19 | 10/21 | 10/24 | 10/26 | 10/28 | 10/31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WOC-A | 0.81 | 0.14 | 0.43 | 0.60 | 0.18 | 0.19 | 0.14 | 0.93 | 0.15 | 0.66 | 0.16 | 0.24 | 0.21 |
| WOC-B | 0.30 | 0.18 | 0.62 | 0.79 | 0.27 | 0.23 | 0.32 | 0.89 | 0.26 | 0.95 | 0.27 | 0.18 | 0.53 |
| NW Trib. | 0.27 | 0.14 | 0.29 | 0.25 | 0.72 | 0.31 | 0.21 | 0.21 | 0.18 | 0.15 | 0.35 | 0.29 | 0.29 |
| S214/W90 | 13.0 | 12.1 | 12.0 | 13.7 | 14.1 | 16.6 | 15.5 | 15.7 | 17.8 | 16.9 | 11.2 | 16.0 | 17.7 |
| S228/W90 | 17.1 | 18.5 | 16.0 | 15.2 | 16.1 | 18.6 | 19.6 | 18.0 | 19.7 | 18.5 | 11.1 | 17.3 | 19.7 |
| 179 | 0.03 | 0.05 | 0.08 | 0.95 | 0.03 | 0.05 | 0.04 | 0.04 | 0.12 | 0.05 | 0.04 | 0.03 | 0.05 |
| 183 | 0.02 | 0.02 | 0.02 | 0.05 | 0.02 | 0.03 | 0.02 | 0.04 | 0.04 | 0.01 | 0.02 | 0.01 | 0.01 |
| 186 | 2.8 | 3.3 | 3.5 | 3.1 | 2.6 | 3.2 | 3.7 | 3.7 | 4.1 | 4.0 | 2.9 | 3.3 | 3.3 |
| 191 | 70.0 | 76.5 | 76.2 | 60.2 | 65.8 | 71.6 | 88.6 | 84.0 | 87.7 | 86.8 | 63.6 | 81.1 | 88.1 |
| 196 | 6.2 | 11.4 | 14.9 | 15.8 | 13.1 | 20.8 | 16.3 | 21.6 | 21.3 | 23.4 | 10.4 | 13.2 | 14.7 |
| 201 | 0.66 | 0.89 | 0.86 | 0.69 | 0.63 | 0.75 | 0.96 | 0.90 | 0.96 | 0.93 | 0.80 | 0.88 | 0.75 |
| 456 | 0.07 | 0.04 | 0.37 | 0.19 | 0.15 | 0.02 | 0.01 | 0.01 | 0.03 | 0.02 | 0.04 | 0.02 | 0.02 |
| 457 | 0.11 | 0.04 | 0.19 | 0.05 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 | 0.04 | 0.01 | 0.01 |
| Precip. (cm) | 0.00 | 0.00 | 0.00 | 5.18 | 0.18 | 0.00 | 0.38 | 0.00 | 0.00 | 0.03 | 5.41 | 0.00 | 0.00 |

Table 5. Strontium-90 activity (dpm/ml) as a function of time in ground-water samples from four wells on the perimeter of SWDA 4

| Date | Well 196 | Well 191 | Well 186 | Well 179 |
|---|---|---|---|---|
| 10/77 (average of 13 measurements) | 15.6 | 76.9 | 3.35 | 0.12 |
| 9/74 | 31.1 | 68.8 | 7.33 | -- |
| 10/73 | 36.4 | -- | 8.5 | -- |
| 8/73 | -- | 80.5 | -- | $\leq$ 0.1 |
| 7/64 | 84.3 | -- | -- | -- |
| 8/59 - 1/60 (composite) | 56 | 22 | -- | -- |

Sources: Lomenick and Cowser 1961; Gera (unpublished manuscript, 1964, Health Physics Division, ORNL); Duguid 1975; Duguid 1976; and this report.

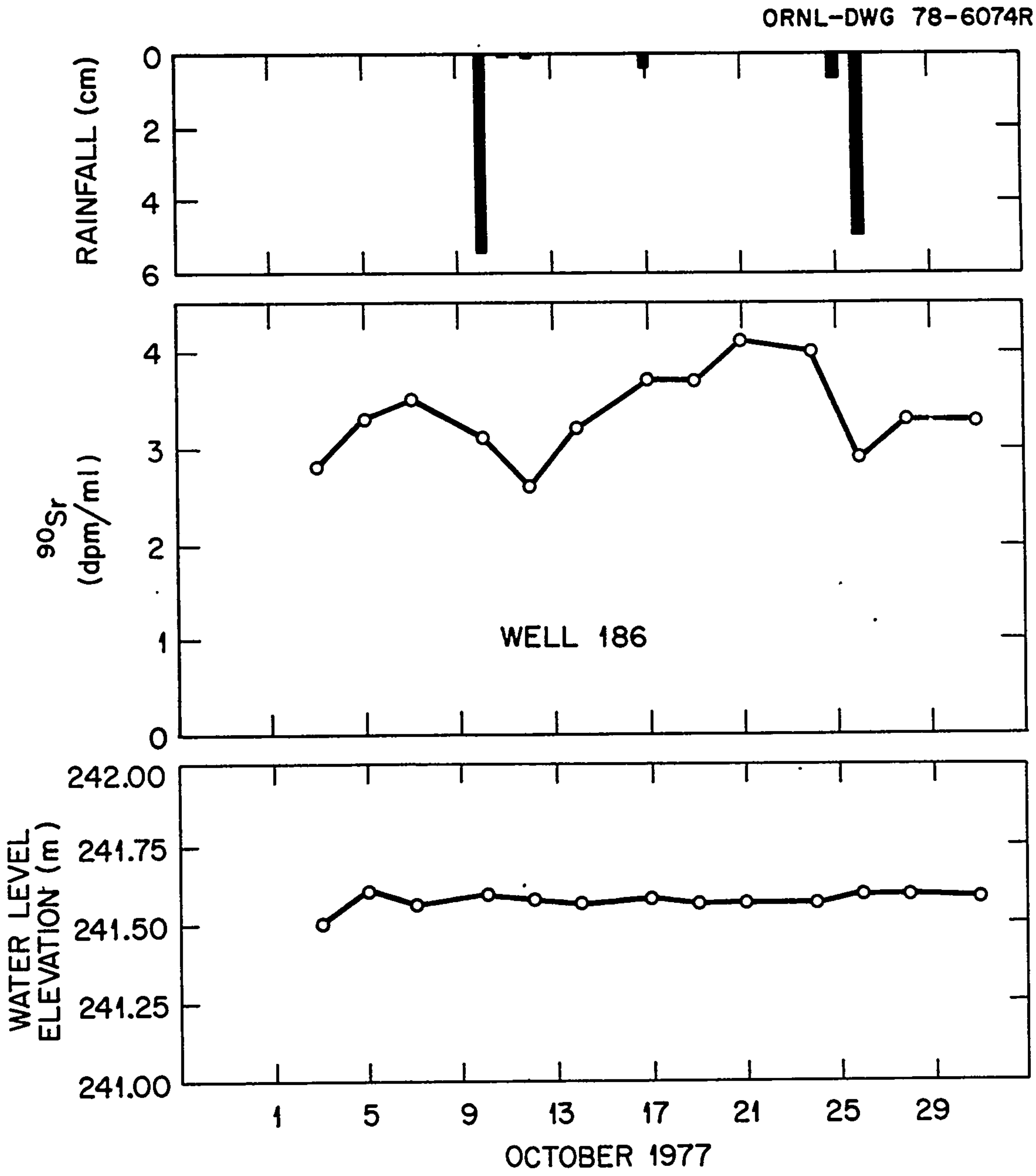


Fig. 4. Comparison of $^{90}$Sr activity and water-level elevation in well 186 during October 1977.

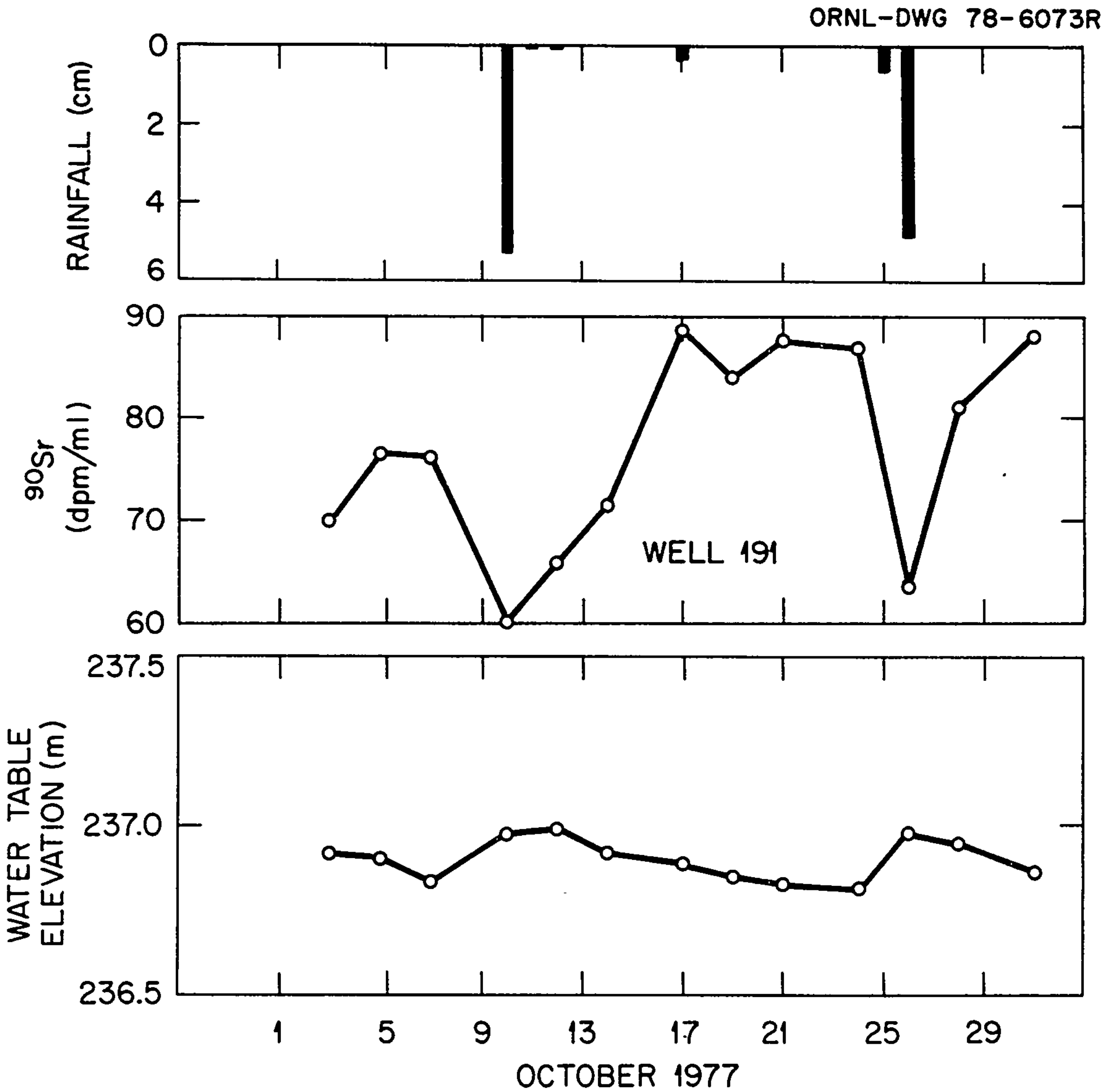


Fig. 5. Comparison of $^{90}Sr$ activity and water-level elevation in well 191 during October 1977.

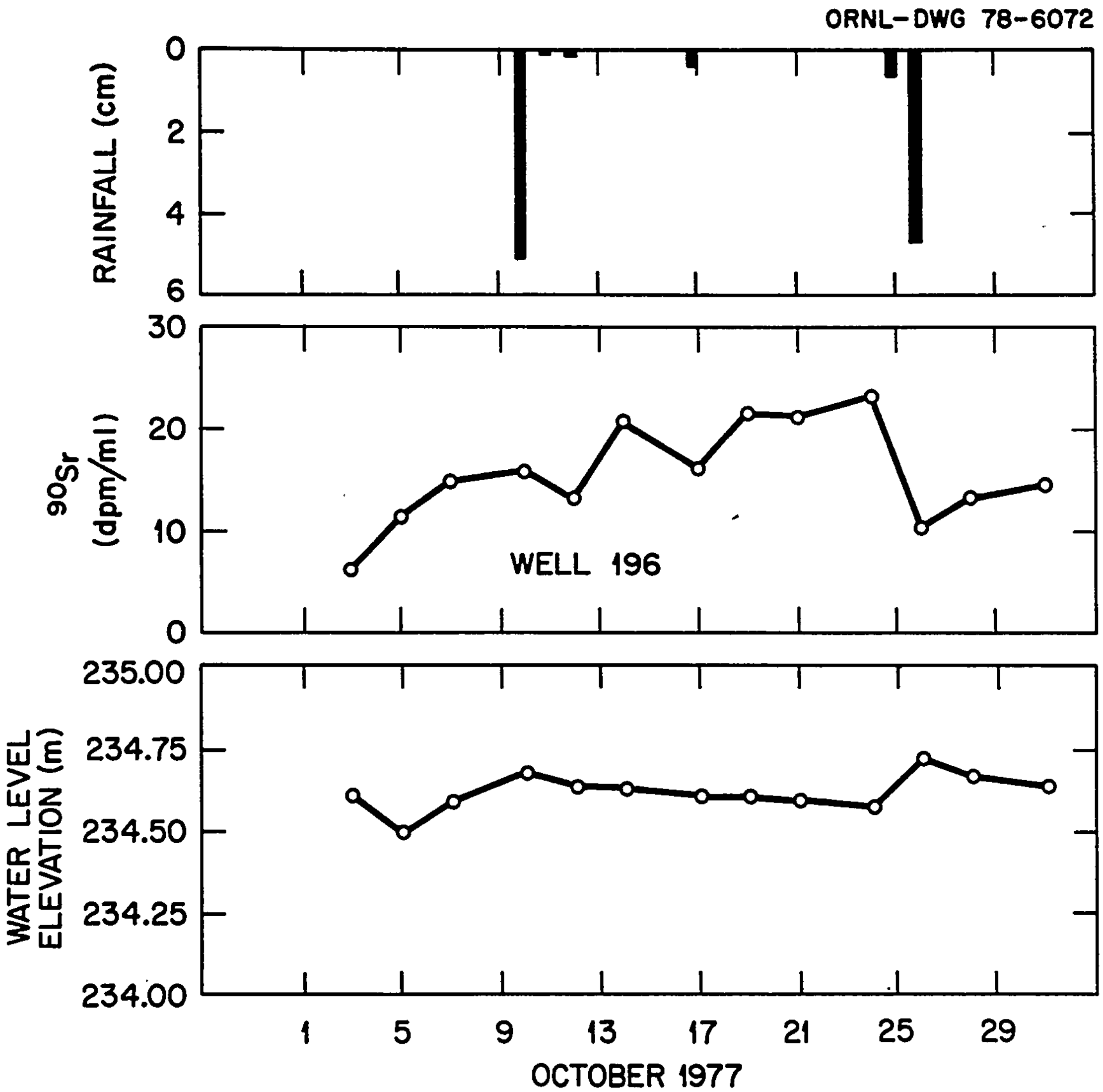


Fig. 6. Comparison of $^{90}Sr$ activity and water-level elevation in well 196 during October 1977.

time (Table 6). Not only does this indicate that there has been no recent increase in $^{90}Sr$ discharge from SWDA 4, but it also serves as a measure of the short-term effectiveness of the surface-water diversion system (Fig. 7) which was installed in 1975 to reduce surface-water infiltration and radionuclide discharge from the disposal area.

The analyses of White Oak Creek water samples taken at station A, when compared with those for samples taken at station B (Table 4; Fig. 3), demonstrate that a significant $^{90}Sr$ activity is present in White Oak Creek before it flows past SWDA 4. The increase in $^{90}Sr$ concentration in the creek water between stations A and B may be attributed to $^{90}Sr$ discharged from SWDA 4 and from the contaminated floodplain east of SWDA 4. The soil in the floodplain has been contaminated by the discharge of the stream which flows along the south boundary of SWDA 4 (Fig. 3) and by seepage from the disposal area (Duguid 1976). Contamination also occurred when much of the area was flooded by the intermediate pond (Fig. 3), formed by a dam which was constructed in the spring of 1944 to form an intermediate retention pond upstream from White Oak Lake. It was breached by high water in September 1944; a residual pond existed behind the dam until the early 1950s.

The $^{90}Sr$ concentrations in White Oak Creek at stations A and B have been plotted as a function of sampling date in Fig. 8. Activity levels at the two stations generally fluctuate in a sympathetic manner, suggesting that a $^{90}Sr$ source (or sources) above SWDA 4 is discharging to the creek at a nonuniform rate and that the $^{90}Sr$ input to the creek as it passes SWDA 4 is fairly constant. Although stream flow measurements at stations A and B are required to quantify the $^{90}Sr$ discharges in the creek at these points, the stream flow does not increase appreciably from station A to station B. Therefore, the relative $^{90}Sr$ activity levels are a fairly good measure of relative $^{90}Sr$ discharges in White Oak Creek. These measurements indicate that a large proportion of the $^{90}Sr$ passing monitoring station 3 is present in White Oak Creek before it passes SWDA 4. This evidence, together with the lack of evidence for increased transport of $^{90}Sr$ from SWDA 4, suggests an investigation of potential $^{90}Sr$ sources in

Table 6. Strontium-90 concentration (dpm/ml) in surface stream south of SWDA 4

| Date | Surface stream #1 S214/W90 | Surface stream #2 S228/W90 | Average |
|---|---|---|---|
| 12/73 | 17.5 | 16.8 | 17.1 |
| 1/74 | 20.2 | 19.2 | 19.7 |
| 9/74 | 26.6 | 11.8 | 19.2 |
| 9/75 | Surface-water diversion system installed. | | |
| 4/76 | 17.7 | 7.2 | 12.5 |
| 10/76 | 22.3 | 19.2 | 20.7 |
| 2/77 | 17.8 | 17.6 | 17.7 |
| 10/77 | 14.8 | 17.3 | 16.1 |

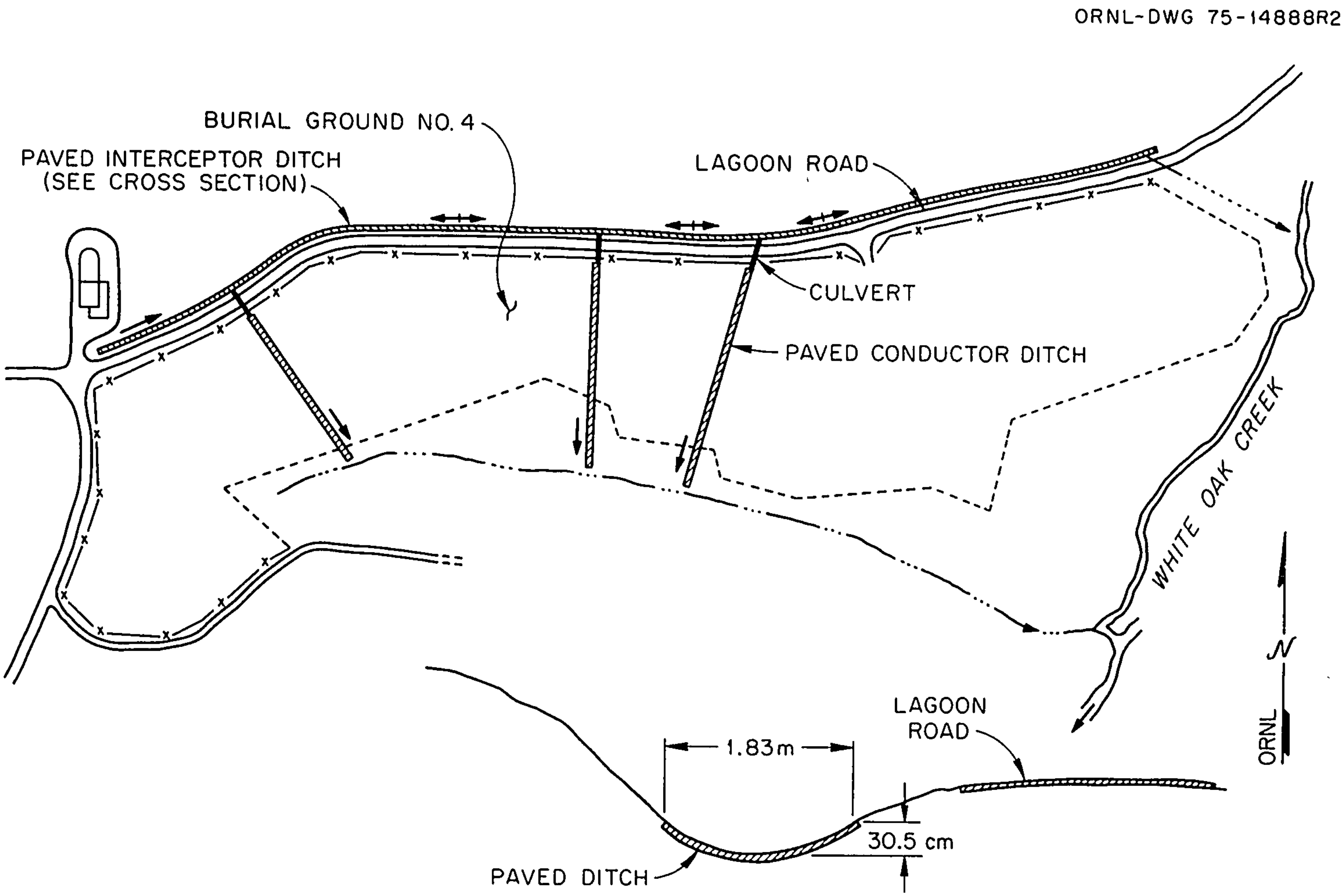


Fig. 7. Surface-runoff diversion system for SWDA 4.

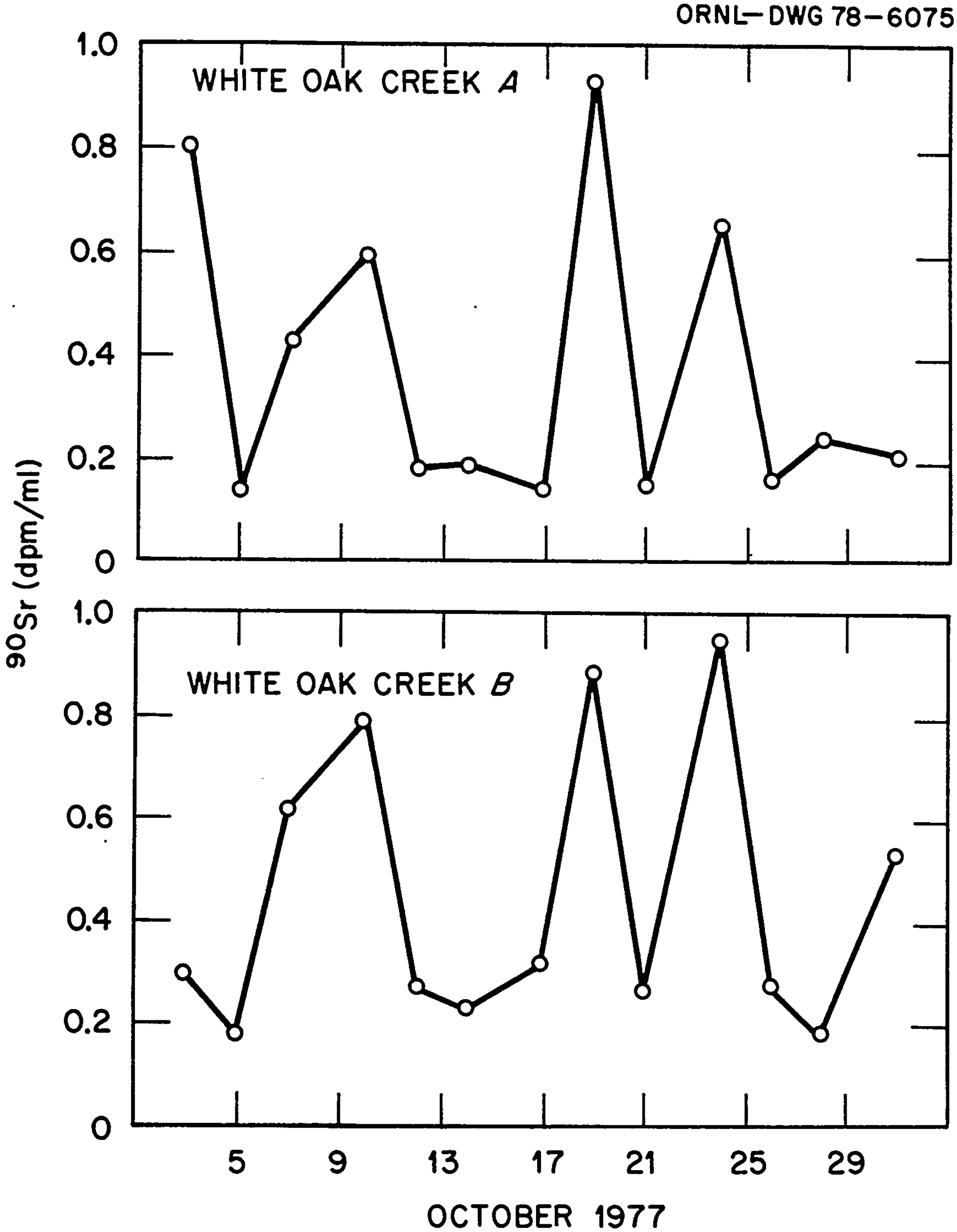


Fig. 8. Strontium-90 concentrations at White Oak Creek stations A and B, October 1977.

the vicinity of White Oak Creek above SWDA 4 in order to account for the recent increases in $^{90}Sr$ passing monitoring station 3.

## ACTIVITY LEVELS AND SOURCES OF $^{90}SR$ IN WHITE OAK CREEK BETWEEN MONITORING STATIONS 2 AND 3

A comprehensive sampling program, designed to identify and evaluate all $^{90}Sr$ sources that make significant contributions to White Oak Creek in its reach between monitoring stations 2 and 3, was carried out in December 1977. A water-sampling schedule was set up which would yield $^{90}Sr$ concentration profiles in this reach of the creek on selected days within the month. A sample profile consisted of White Oak Creek water samples collected on a single day at 150-m intervals between monitoring stations 2 and 3, plus water samples from all tributaries and ORNL plant effluents entering this segment of the creek, which is approximately 1.75 km in length (Fig. 9). Seven sample profiles were collected during the month. In addition, ground-water samples were collected at various times from selected wells adjacent to the creek. Samples of surface-runoff water were also collected at several sites. Daily precipitation was recorded at a location within the study area.

All water samples were analyzed for $^{90}Sr$ activity. Duplicate water samples were collected at each White Oak Creek station for the sample profiles obtained on December 2 and on December 5, 1977. For each station, one of the duplicate samples was filtered through Whatman filter paper No. 42. Both filtered and unfiltered water samples were analyzed for $^{90}Sr$ activity; in only two cases did the analytical pairs differ by more than experimental uncertainty. The remainder of the routine water samples collected during the investigation were not filtered.

The longitudinal profiles of $^{90}Sr$ concentration in White Oak Creek were devised to locate stream intervals where major $^{90}Sr$ contributions occur. Activity levels of $^{90}Sr$ in the other water

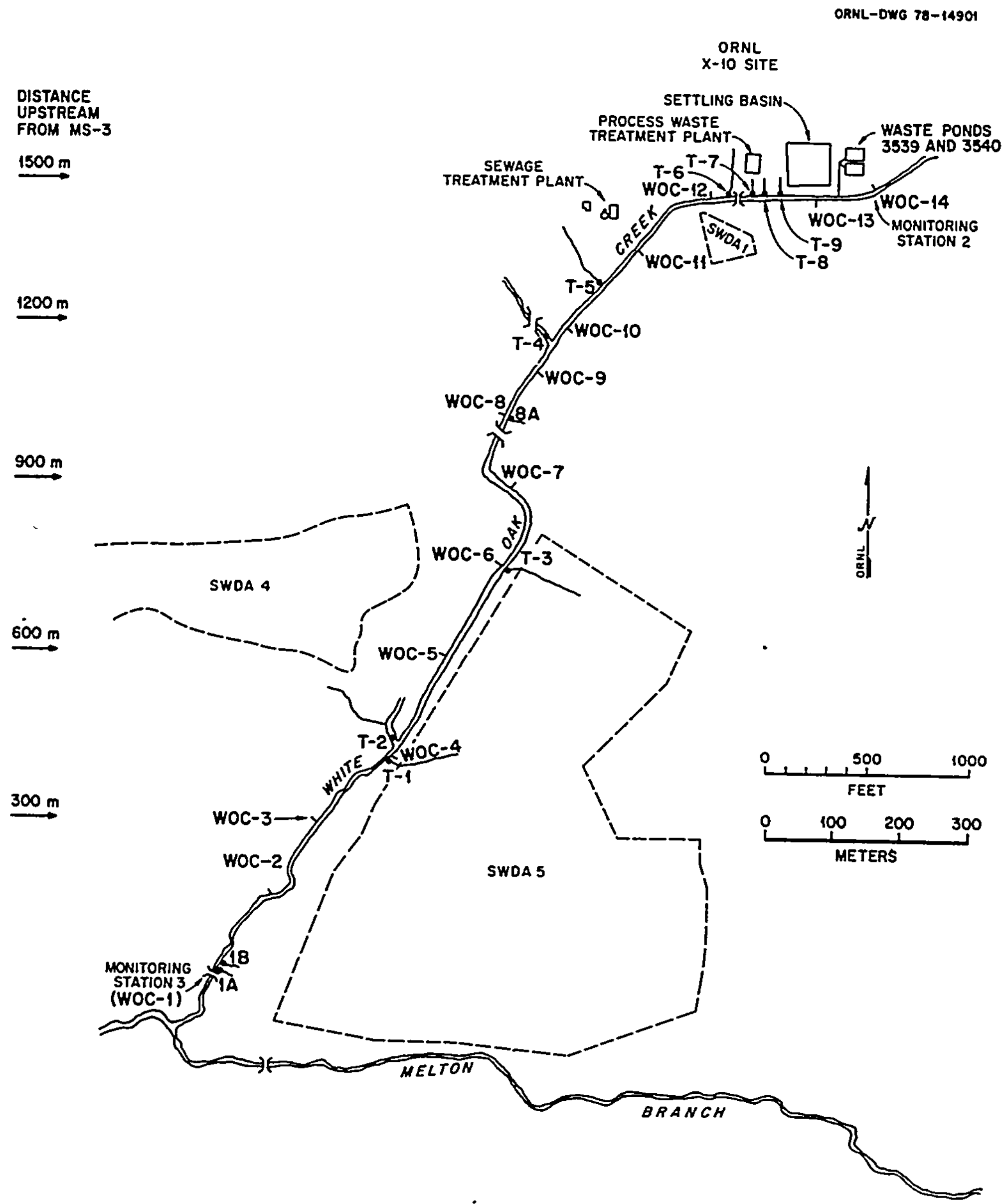


Fig. 9. Locations of White Oak Creek (WOC) and tributary (T) collection sites between monitoring stations 2 and 3.

samples were obtained to assist in the identification and evaluation of the $^{90}Sr$ sources to White Oak Creek in this reach. The profile sampling program covered a one-month period in order to obtain representative data under a range of field conditions, and to make use of Operations Division stream-monitoring data which are available on a monthly basis. Some of the ground-water and surface-runoff water samples were collected subsequent to December 1977.

## Longitudinal Profiles of $^{90}Sr$ Activity in White Oak Creek

Analytical results for each of the seven sample profiles are presented in Table 7; sample locations are shown in Fig. 9. Longitudinal profiles of $^{90}Sr$ concentration in White Oak Creek during December 1977 are presented in Appendix A, Figs. A-1 through A-7. The figures also show the $^{90}Sr$ activities in tributaries and ORNL plant effluents at points just above their confluence with the creek. Information regarding the source of the water in each of the tributaries and plant effluents is given in Table 8.

The $^{90}Sr$ concentration profiles fall into two general categories, hereafter referred to as normal profiles (Figs. A-1, A-2, A-3, A-5, A-7) and perturbed profiles (Figs. A-4 and A-6). Data from the five normal profiles have been combined to yield an average normal profile (Fig. 10), whose features may be readily accounted for by input from tributaries and plant effluents. Beginning at monitoring station 2 and proceeding downstream, there is an initial small but detectable increase in $^{90}Sr$ activity due to ORNL plant effluents and surface drainage. Although the $^{90}Sr$ concentrations in the discharges from T-6, T-7, and T-9 are usually much higher than the levels normally present in this segment of White Oak Creek (Fig. 10), the low flow rates result in an insignificant $^{90}Sr$ discharge to White Oak Creek from these sources.

Further downstream the $^{90}Sr$ activity in White Oak Creek rises sharply under normal conditions (Fig. 10), due to the discharge from T-5. The water in this tributary is primarily effluent from the Sewage

Table 7. Concentrations of $^{90}Sr$ (dpm/ml) in water samples from White Oak Creek (WOC) and tributaries (T), December 1977

| Sample | 12-2 | 12-5 | 12-9 | 12-14 | 12-16 | 12-20 | 12-28 |
|---|---|---|---|---|---|---|---|
| WOC-1 | 0.40 | 0.39 | 0.50 | 0.49 | 0.36 | 0.43 | 0.66 |
| WOC-1A | 0.85 | 0.75 | 0.80 | 0.98 | 1.1 | 1.1 | -- |
| WOC-1B | 0.62 | 0.58 | 0.63 | 0.84 | 0.85 | 0.96 | 1.3 |
| WOC-2 | 0.39 | 0.39 | 0.44 | 0.62 | 0.37 | 0.49 | 0.67 |
| WOC-3 | 0.35 | 0.40 | 0.43 | 0.67 | 0.44 | 0.50 | 0.68 |
| WOC-4 | 0.24 | 0.27 | 0.44 | 0.56 | 0.46 | 0.44 | 0.39 |
| WOC-5 | 0.23 | 0.24 | 0.41 | 0.38 | 0.23 | 0.28 | 0.43 |
| WOC-6 | 0.20 | 0.22 | 0.30 | 0.43 | 0.31 | 0.28 | 0.26 |
| WOC-7 | 0.19 | 0.22 | 0.36 | 0.39 | 0.31 | 0.33 | 0.20 |
| WOC-8 | 0.17 | 0.30 | 0.33 | 0.93 | 0.39 | 0.31 | 0.17 |
| WOC-8A | 2.0 | 1.6 | 2.6 | 2.3 | 2.9 | 3.0 | 2.0 |
| WOC-9 | 0.25 | 0.27 | 0.40 | 0.93 | 0.38 | 0.75 | 0.20 |
| WOC-10 | 0.13 | 0.18 | 0.23 | 0.83 | 0.44 | 1.0 | 0.12 |
| WOC-11 | 0.05 | 0.12 | 0.07 | 0.99 | 0.07 | 1.0 | 0.08 |
| WOC-12 | 0.12 | 0.09 | 0.09 | 0.72 | 0.10 | 0.98 | 0.08 |
| WOC-13 | 0.12 | 0.05 | 0.08 | 0.77 | 0.10 | 0.96 | 0.06 |
| WOC-14 | 0.06 | 0.05 | 0.06 | 0.05 | 0.05 | 0.04 | 0.03 |
| T-1 | 0.08 | 0.06 | 0.08 | 0.10 | 0.08 | 0.10 | 0.10 |
| T-2 | 9.5 | 6.6 | 7.9 | 5.8 | 8.9 | 7.6 | 6.8 |
| T-3 | 0.003 | < 0.01 | 0.014 | 0.01 | 0.04 | 0.18 | 0.11 |
| T-4 | 0.18 | 0.10 | 0.24 | 0.14 | 0.15 | 0.19 | 0.15 |
| T-5 | 5.2 | 4.8 | 6.0 | 5.1 | 6.0 | 5.8 | 3.1 |
| T-6 | 0.22 | 1.3 | 0.91 | 0.17 | 0.47 | 0.14 | 0.49 |
| T-7 | 0.66 | 0.69 | 0.34 | 0.17 | 0.18 | 0.14 | 0.13 |
| T-8 | 0.008 | -- | 0.07 | 0.04 | -- | 0.02 | -- |
| T-9 | 0.55 | 0.19 | 0.11 | 0.05 | 0.08 | 0.20 | 0.76 |

Table 8. Tributaries and plant effluents to White Oak Creek between monitoring stations 2 and 3. For locations, see Fig. 9.

| | |
|---|---|
| WOC-1A,1B | Drainage from floodplain area, east of White Oak Creek. |
| T-1 | Stream drainage from north-central section of SWDA 5. |
| T-2 | Stream drainage south of SWDA 4 plus drainage in former White Oak Creek channel. |
| T-3 | Stream drainage from northernmost section of SWDA 5 and 7500 areas. |
| WOC-8A | Drainage from standing water in floodplain area east of White Oak Creek. |
| T-4 | Northwest tributary to White Oak Creek; drainage from Bethel Valley area, including SWDA 3. |
| T-5 | Surface drainage from ORNL plant area plus Sewage Treatment Plant effluent. |
| T-6 | Surface drainage from ORNL plant area. |
| T-7 | Surface drainage from ORNL plant area plus Process Waste Treatment Plant effluent. |
| T-8 | Steam Plant effluent; intermittent. |
| T-9 | Surface drainage from ORNL plant area. |

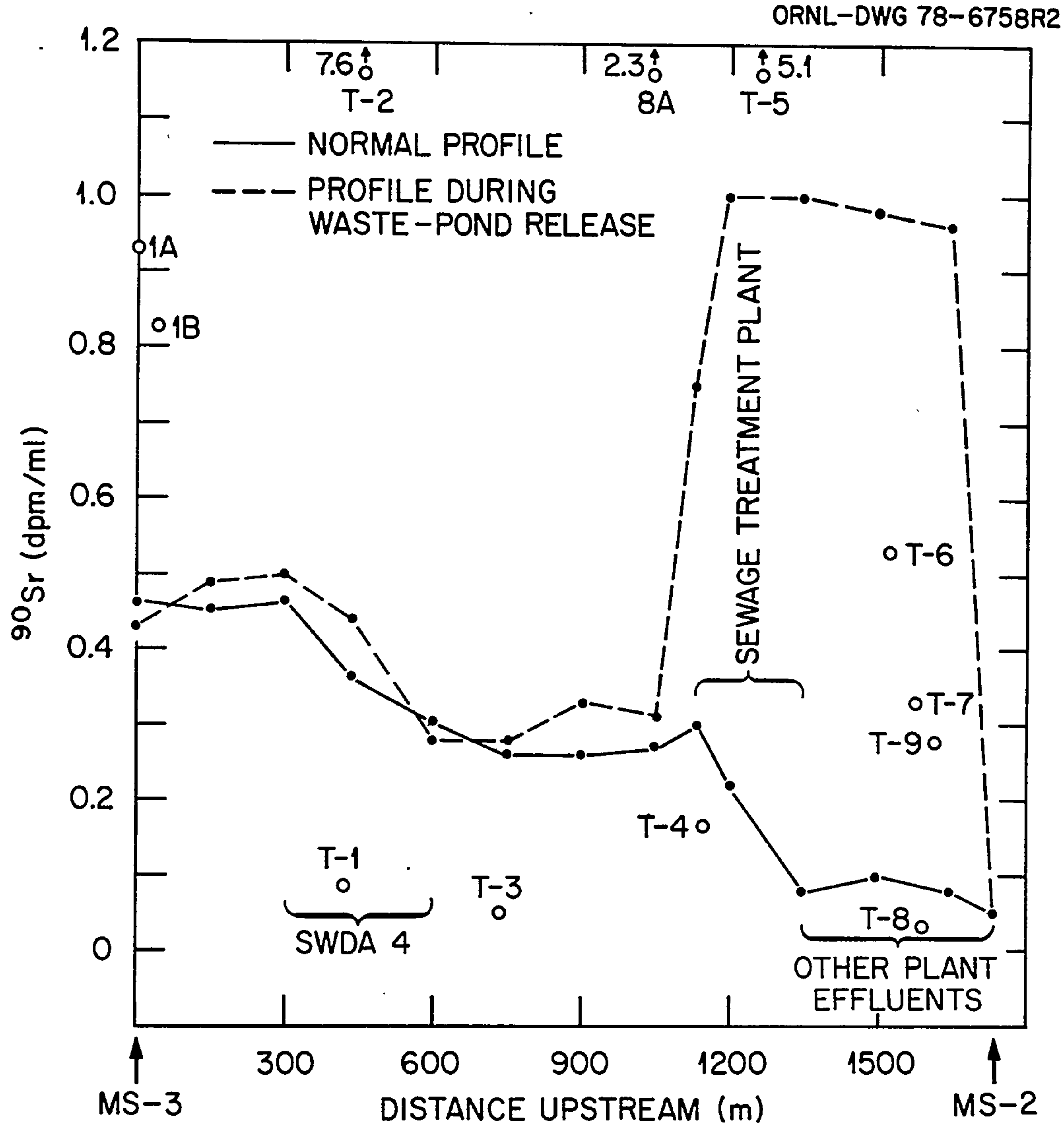


Fig. 10. Normal and perturbed longitudinal profiles of $^{90}$Sr activity in White Oak Creek during December 1977.

Treatment Plant, diluted to a small degree by surface runoff. The $^{90}Sr$ concentration in the discharge from T-5 to the creek is consistently around 5 dpm/ml (Table 7), and the rate of flow is considerably higher than that of tributaries T-6, T-7, and T-9. Lomenick et al. (1962) reported a mean $^{90}Sr$ concentration of 3.8 dpm/ml in the Sewage Treatment Plant effluent for the period May-October 1961.

Downstream from T-5 the $^{90}Sr$ activity level in the creek decreases somewhat (Fig. 10) due to the discharge from the northwest tributary (T-4), which is the largest tributary that enters White Oak Creek in the study reach. While the $^{90}Sr$ concentration in the discharge from T-4 is normally well below that of White Oak Creek at the point of confluence (Fig. 10), there is nevertheless a significant $^{90}Sr$ discharge from this source. Most of the $^{90}Sr$ in the northwest tributary probably comes from SWDA 3. Tributary WOC-8A represents another source of $^{90}Sr$ discharge to this segment of White Oak Creek (Fig. 9). It drains an area of standing water in the floodplain adjacent to the creek. Although the $^{90}Sr$ activity of this effluent is consistently about 2 dpm/ml (Table 7), the discharge to White Oak Creek is insignificant.

The $^{90}Sr$ activity in White Oak Creek increases by approximately 50% in the interval between 300 and 600 m above monitoring station 3 (Fig. 10). This increase reflects the input of $^{90}Sr$ from SWDA 4, which is discharged via the stream that lies to the south of this disposal area (Fig. 3) and enters White Oak Creek at T-2, a former channel of the creek (Fig. 9). Although the $^{90}Sr$ activity of T-2 is the highest of any tributary in the study reach (Table 7), the discharge into the creek is tempered by a pooling effect in the former creek channel. Tributaries T-1 and T-3, which carry drainage from SWDA 5 (Fig. 9), have consistently low $^{90}Sr$ concentrations (Fig. 10) and have a negligible effect on the longitudinal concentration profiles in White Oak Creek.

Within 50 m of monitoring station 3, two small tributaries, WOC-1A and WOC-1B, enter White Oak Creek (Fig. 9). They carry drainage from the floodplain east of the creek. The $^{90}Sr$ activity levels of these waters are consistently much higher than the $^{90}Sr$ activity in White Oak Creek in this interval (Fig. 10). However, the discharges seem to have minimal effect on the longitudinal concentration profiles, possibly because there has been insufficient mixing before the creek was sampled at monitoring station 3 (WOC-1).

The perturbed $^{90}Sr$ concentration profiles are shown in Figs. A-4 and A-6; one of them is shown in Fig. 10 for comparison with the average normal profile. On December 14 (Fig. A-4) and on December 20 (Fig. A-6) the profile of $^{90}Sr$ activity in White Oak Creek is normal from monitoring station 3 to a point about 1050 m upstream. At that point the activity rises sharply, reaching levels several times higher than normal (Fig. 10), but then returns to a normal value at monitoring station 2. All regularly sampled tributaries and plant effluents have normal $^{90}Sr$ concentrations on these dates (Table 7; Figs. A-4 and A-6). It is probable that these activity "spikes" in White Oak Creek are due to intermittent ORNL plant releases that were intercepted during the course of profile sampling in these two cases. Sampling always proceeded in an upstream direction. The releases apparently occur between monitoring station 2 and the next White Oak Creek sampling point, which is only 83 m downstream. The only possible source in this short interval is the effluent from Waste Ponds 3539 and 3540 (Fig. 9), which receive liquid waste from the Building 4500 complex.

Because of the intermittent nature of the discharge from these waste ponds, the effluent was not included in the course of profile sampling. On December 2, however, after the sampling profile had been completed, a grab sample was obtained from Waste Pond 3540 just before the liquid was released to White Oak Creek. Low-level $^{90}Sr$ analysis yielded 6.0 dpm/ml.

Intermittent releases from the waste ponds might also explain the $^{90}Sr$ activity relationships at White Oak Creek stations A and B (Fig. 3) observed during October 1977 (Fig. 8). The sympathetic fluctuations in $^{90}Sr$ concentrations at the two stations suggested that a $^{90}Sr$ source upstream from SWDA 4 was discharging to the creek at a nonuniform rate; the upstream source could have been the waste ponds.

When relatively high $^{90}Sr$ concentrations were observed at both stations A and B, an activity "spike" was apparently being intercepted.

## Transport of $^{90}Sr$ by Suspended Matter

An important consideration in the discharge of $^{90}Sr$ by White Oak Creek is the amount of this radionuclide that might be transported by suspended matter. The sorption of $^{90}Sr$ on suspended sediment is relatively low compared to that of other radionuclides, and is strongly affected by the concentration of stable alkaline-earth ions, principally calcium and magnesium, in the water. Carrigan et al. (1967) determined the sorption of strontium by Clinch River sediments. In demineralized water containing $^{85}Sr$ as a radioactive tracer ($5.0 \times 10^{-5}$ meq of strontium in 200 ml), a mean value of 49.3 ± 1.7% of the strontium was removed by 0.1 g of each of 11 sediment samples. The solution contained 0.022 meq (Ca + Mg). When Oak Ridge tap water was substituted for demineralized water, the calcium concentration in the solution was 26 ppm and the magnesium concentration was 8 ppm, which resulted in a solution containing 0.39 meq (Ca + Mg) in 200 ml. The sorption of strontium in this system was reduced to 2.50%. This effect was explained by assuming that the sorption of strontium by the sediment in the tap water system was reduced in proportion to the reduction in the Sr/(Ca + Mg) ratio in the tap water system as compared to the same ratio in the distilled water system.

The probable reduction in strontium sorption by sediments in White Oak Creek due to the calcium and magnesium present in the creek water can be calculated in an analogous manner, assuming that White Oak Creek sediments are similar to Clinch River sediments. The White Oak Creek water samples collected at stations A and B (Fig. 3) during October 1977 were analyzed for calcium and magnesium by atomic absorption spectrophotometry (Table 9). For the water samples collected at the two sites, the mean calcium concentration is 41.3 ppm and that of magnesium is 8.39 ppm, which corresponds to 0.550 meq (Ca + Mg) in White Oak Creek water. If the sorption experiment involving Clinch River sediments (Carrigan et al. 1967) had been carried out in White Oak

Table 9. Calcium and magnesium concentrations (ppm) in White Oak Creek water samples collected at stations A and B (Fig. 3), October 1977

| Date | Station A Ca | Station A Mg | Station B Ca | Station B Mg |
|---|---|---|---|---|
| 10/03 | 39.0 | 8.00 | 40.8 | 8.20 |
| 10/05 | 39.0 | 8.00 | 38.4 | 8.20 |
| 10/07 | 40.0 | 8.80 | 39.6 | 9.00 |
| 10/10 | 39.6 | 7.60 | 39.2 | 7.40 |
| 10/12 | 41.4 | 7.80 | 42.4 | 8.00 |
| 10/14 | 42.2 | 8.40 | 42.6 | 8.20 |
| 10/17 | 39.2 | 7.80 | 40.8 | 7.80 |
| 10/19 | 45.8 | 9.00 | 38.4 | 10.8 |
| 10/21 | 44.6 | 9.40 | 45.4 | 9.40 |
| 10/24 | 38.6 | 9.00 | 60.4 | 10.4 |
| 10/26 | 40.2 | 7.20 | 38.8 | 7.20 |
| 10/28 | 37.8 | 7.80 | 40.0 | 7.80 |
| 10/31 | 40.8 | 8.60 | 40.2 | 8.20 |

Creek water, the sorption of strontium should have been reduced to about 2.0%.

Lomenick (in Morton, 1963) used a sampling train that separates suspended solids directly from creek water to study the transport of suspended solids and their associated activity in White Oak Creek. Eight operating runs, ranging from 1 to 4 hr in duration, were made near monitoring station 3. In six of the eight runs more than 98% of the $^{90}Sr$ was associated with the liquid phase (materials not retained by 0.45-μm Millipore filter). The creek flow during one of these runs was 57 cfs (1.61 $m^3/sec$), nearly six times the average for White Oak Creek at the sampling point. For two of the eight runs values of 92.9 and 75.5% of the $^{90}Sr$ were found associated with the liquid phase. In the latter case the creek flow was only 7.8 cfs (0.22 $m^3/sec$), but the concentration of suspended solids in the water was unusually high. It was pointed out that construction work in and around White Oak Creek, which resulted in removal of soil cover, may have accounted in part for the extremely high concentrations of suspended solids observed in some of the runs. Therefore, although significant quantities of $^{90}Sr$ can be transported downstream by suspended sediments when the creek has an unusually high suspended-solids load, these conditions may not be due to natural events.

Soil on the contaminated floodplains within the study area provides a potential source of material that might be mobilized under very severe natural conditions to produce an unusually high suspended-solids load in White Oak Creek. However, such conditions were not present during the period of this investigation. Because of the low sorption of $^{90}Sr$ on sediments and the high concentations of calcium and magnesium in White Oak Creek, it seems reasonable to conclude that the transport of $^{90}Sr$ by suspended matter was very small compared to that which was transported in solution.

## Strontium-90 Contributions from Direct Surface Runoff

The general features of the normal longitudinal profiles of $^{90}Sr$ activity in White Oak Creek can be accounted for by discharges from tributaries and plant effluents. Strontium-90 may be discharged to the creek by other means including direct surface runoff, either diffuse or in discrete channels, during storm events. Although the low sorption of strontium by sediment suggests that $^{90}Sr$ in surficial soil and other materials would be rapidly depleted, such source areas could be replenished periodically by leaks and stream overflow onto floodplains. Therefore, direct surface-runoff waters to tributaries and to White Oak Creek may have significant $^{90}Sr$ activity levels. This possibility was investigated as a part of the comprehensive water-sampling program carried out in the study area between monitoring stations 2 and 3.

A surface-runoff water collector (Fig. 11) was designed and constructed. Collectors were installed at various sites in the study area during December 1977 and January 1978 (Fig. 12). Each was mounted on a slope, supported by wooden stakes driven into the ground. Eleven water samples were obtained through the use of a collector (Table 10); three additional samples were collected directly from discrete channel flow which was observed to be entering White Oak Creek during or just after a storm event.

Activity levels of $^{90}Sr$ in the water samples (Table 10) are shown at the collection sites in Fig. 12. Only at location SR-11A, approximately 1300 m upstream from monitoring station 3, is the $^{90}Sr$ activity in surface runoff more than marginally above background levels. Samples SR-10A and SR-11A were collected from channels in which the runoff was observed to be flowing directly into White Oak Creek from a floodplain to the east, just after a storm event. The $^{90}Sr$ activity detected in SR-11A was probably acquired by the runoff water as it flowed across the floodplain; that aspect will be considered in the following section of this report.

Some of the surface-runoff water samples near and immediately upstream from monitoring station 3 were collected on slopes that are as much as 100 m from White Oak Creek (Fig. 12). This runoff becomes a part of the surface drainage of the intervening floodplain areas before

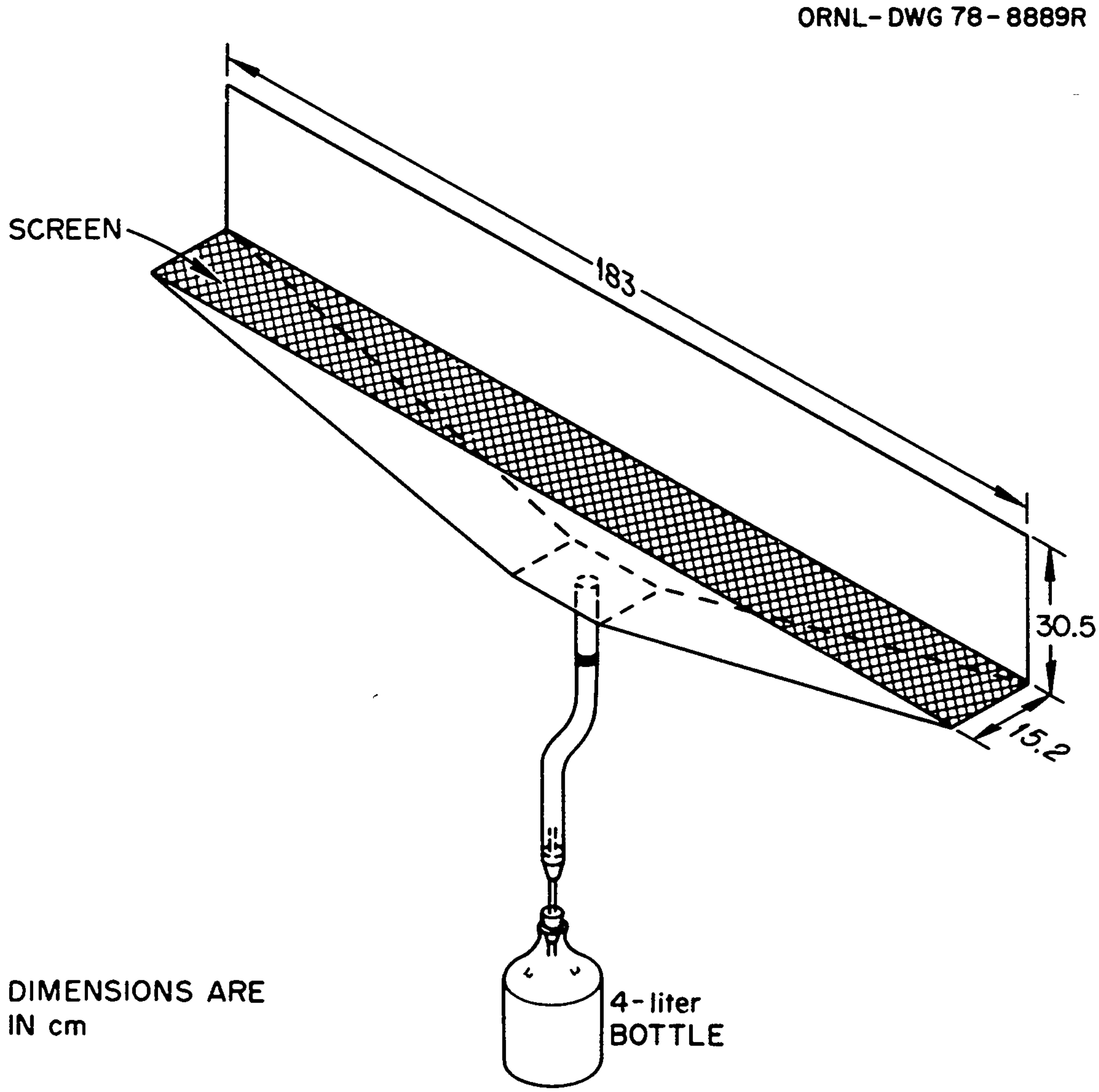


Fig. 11. Surface-runoff water collector.

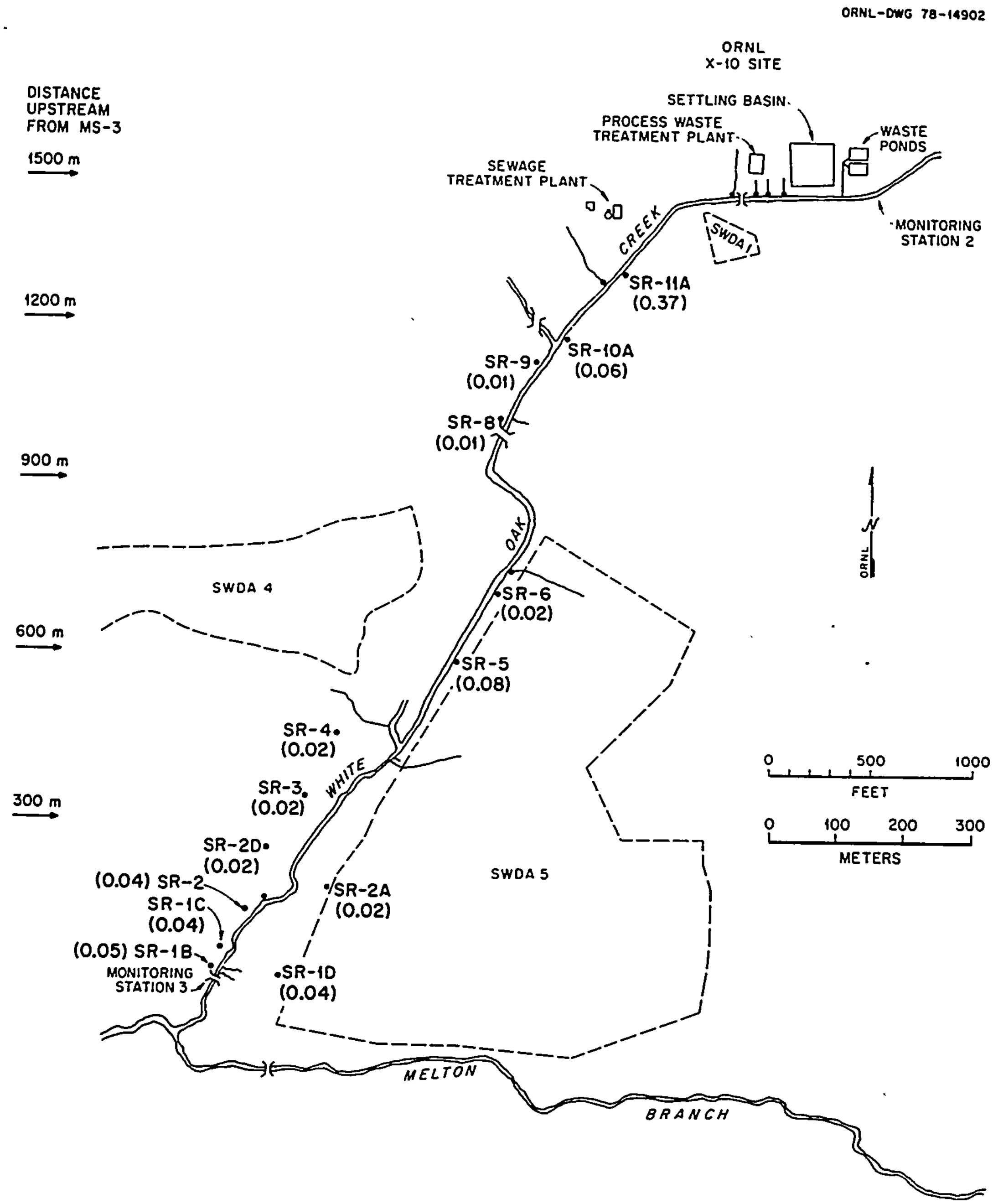


Fig. 12. Surface-runoff (SR) collection sites and $^{90}Sr$ activities (dpm/ml) in water samples collected.

Table 10. Surface-runoff water samples collected in the vicinity of White Oak Creek, including $^{90}Sr$ concentrations (dpm/ml). For sample locations, see Fig. 12.

| Sample | Collection method | Collection period | $^{90}Sr$ |
|---|---|---|---|
| SR-1B | collector | 12/16/77-12/19/77 | 0.05 ± 0.02 |
| SR-1C | collector | 12/31/77-1/8/78 | 0.04 ± 0.02 |
| SR-1D | collector | 12/16/77-12/19/77 | 0.04 ± 0.01 |
| SR-2 | collector | 12/30/77-12/31/77 | 0.04 ± 0.01 |
| SR-2A | collector | 1/12/78-1/17/78 | 0.02 ± 0.01 |
| SR-2D | collector | 1/12/78-1/17/78 | 0.02 ± 0.01 |
| SR-3 | collector | 1/12/78-1/17/78 | 0.02 ± 0.01 |
| SR-4 | collector | 1/18/78-1/24/78 | 0.02 ± 0.01 |
| SR-5 | channel flow | 1/17/78 | 0.08 ± 0.02 |
| SR-6 | collector | 1/18/78-1/24/78 | 0.02 ± 0.01 |
| SR-8 | collector | 12/3/77-12/5/77 | 0.010 ± 0.006 |
| SR-9 | collector | 12/3/77-12/5/77 | 0.009 ± 0.006 |
| SR-10A | channel flow | 1/25/78 | 0.06 ± 0.01 |
| SR-11A | channel flow | 3/3/78 | 0.37 ± 0.04 |

it enters the creek. In the process, the waters may, in some cases, acquire additional $^{90}Sr$ from sources within the floodplains.

Although surface-runoff water samples were not collected within the ORNL plant area, inferences can be drawn from the $^{90}Sr$ analyses of tributaries T-6 and T-9, which discharge only surface drainage from the plant area (Table 8). The $^{90}Sr$ concentrations in these tributary waters at their points of confluence with White Oak Creek are shown, along with daily precipitation, as a function of sampling date in Fig. 13. The activity in the discharge of T-6, and to some extent in the discharge of T-9, increases markedly after storm events. The source of most of the $^{90}Sr$ activity in these tributaries would seem to be surficial contamination within the plant area. While the activities in the discharges can reach significantly high levels after storm events (Fig. 13), their effect on the $^{90}Sr$ concentration in White Oak Creek is minor compared to the effects of other sources (Fig. 10).

On the basis of the water samples collected during this investigation, it appears that direct surface runoff is not an important source of $^{90}Sr$ discharge to White Oak Creek. The only exceptions may be found where the runoff crosses a contaminated floodplain area and enters the creek through channels cut into the natural levees adjacent to the creek. At present such $^{90}Sr$ discharges cannot be quantified, but it seems that the total amount is minor compared to that from other sources.

Strontium-90 sources in Floodplain Areas

Within the reach of White Oak Creek between monitoring stations 2 and 3 there are four distinct low-lying areas that may become flooded by creek water during periods of heavy rainfall. Downstream from monitoring station 2, the first of these (floodplain no. 1) is located on the east side of White Oak Creek between the ORNL plant area and the bridge that crosses the creek at Haw Ridge (Fig. 14). Until recently the culverts which carried creek discharge under the bridge were inadequate to accommodate the flow of the creek during intense storm events. At such times, creek water laden with $^{90}Sr$ from plant

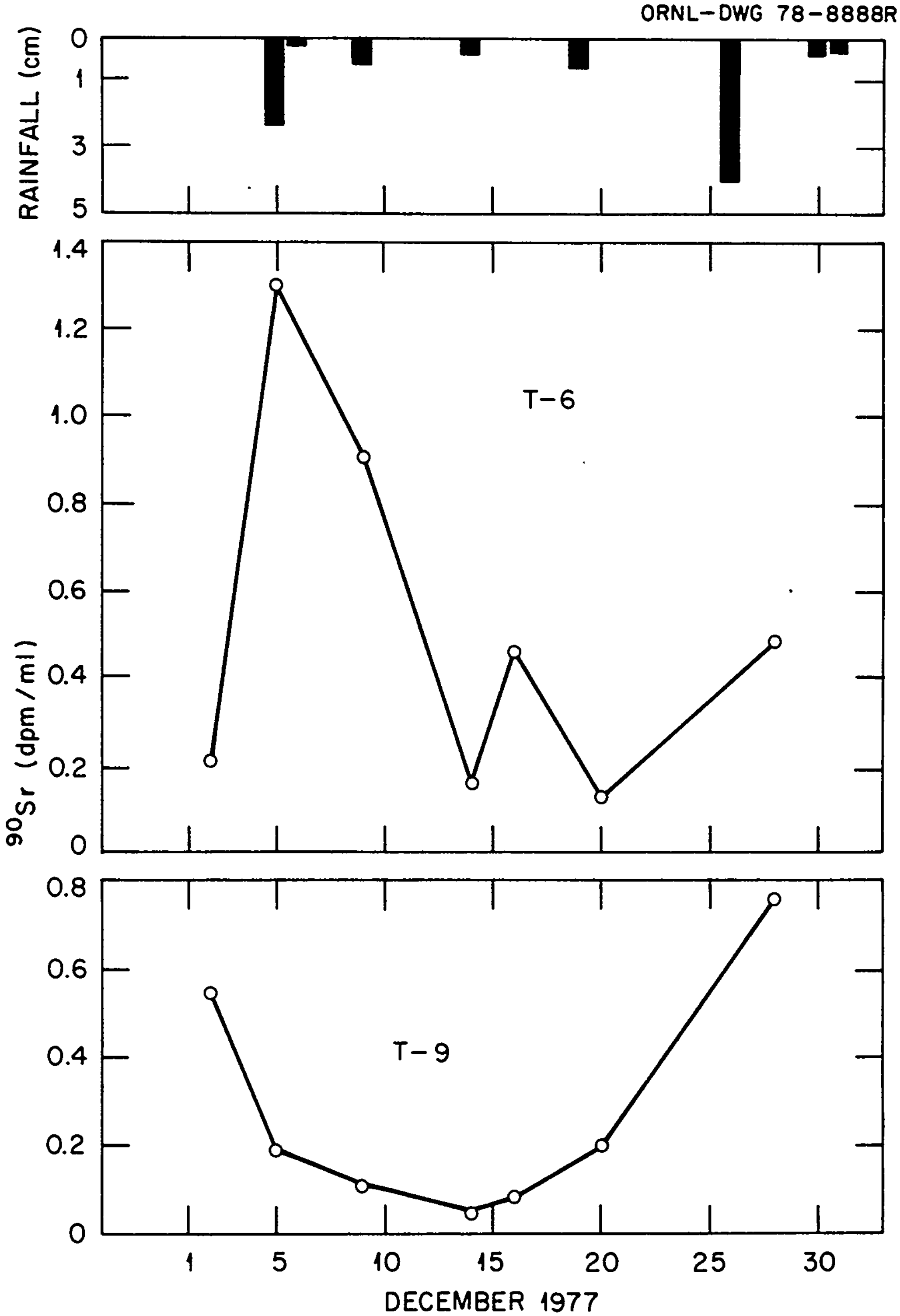


Fig. 13. Comparison of $^{90}$Sr activities in tributaries T-6 and T-9 and daily precipitation during December 1977.

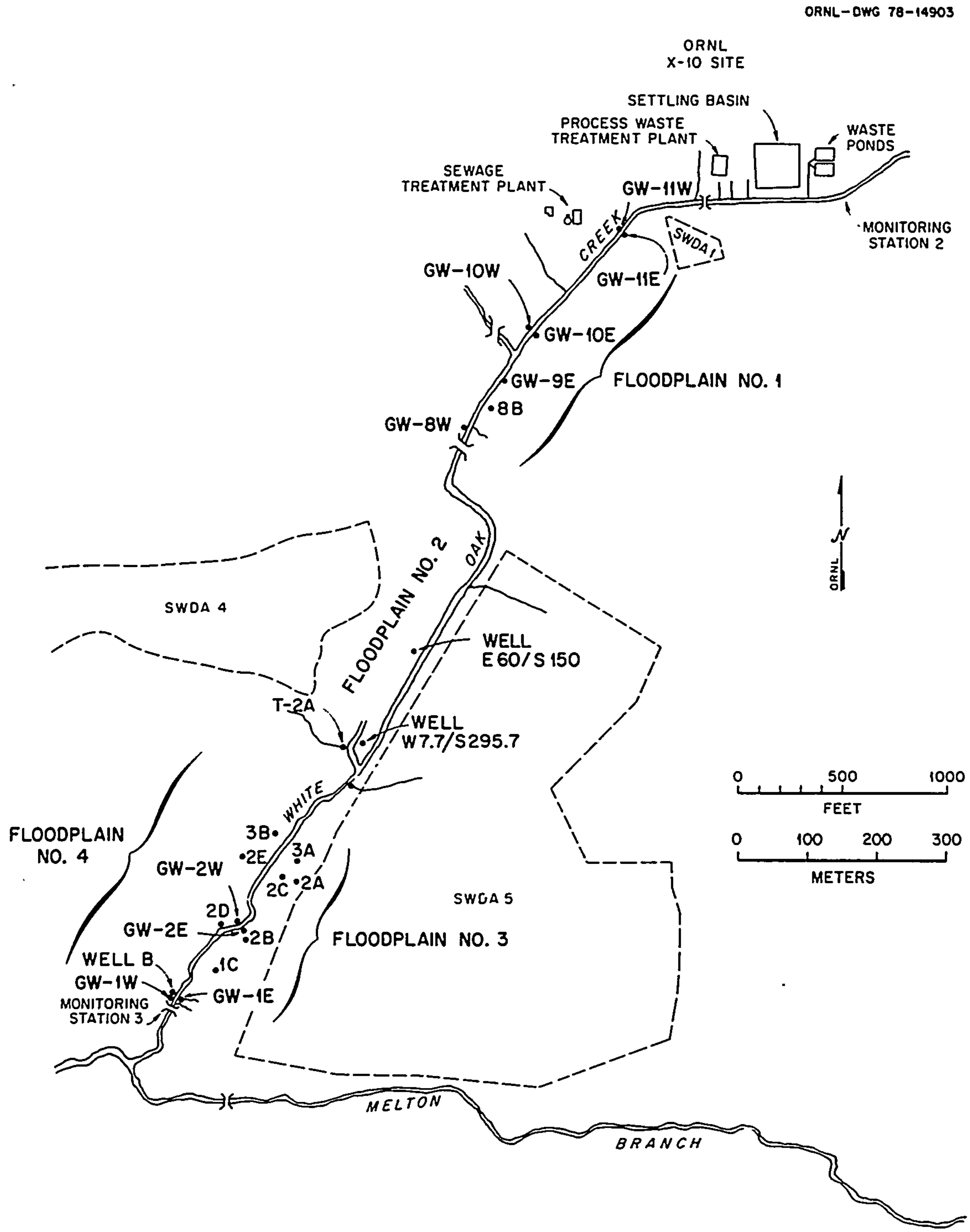


Fig. 14. Locations of floodplain areas in the study reach of White Oak Creek, and the surface- and ground-water collection sites.

effluents, primarily from the former Process Waste Treatment Plant, flowed over floodplain no. 1, contaminating the soil and vegetation. This contamination could serve as a $^{90}Sr$ source for ground water, and for surface-runoff water from Haw Ridge. Through the years, the $^{90}Sr$ activity in the floodplain has been replenished (probably increased) during flooding events. The situation has been substantially alleviated since the installation of the new Process Waste Treatment Plant (April 1976) and the installation of additional and larger culverts under the bridge (October 1977).

Further downstream, a second floodplain is located between SWDA 4 and White Oak Creek (Fig. 14). The lower limit of floodplain no. 2 is marked by the earth dam which formed the intermediate retention pond (Fig. 3). Radioactive contamination of the soil and ground waters in this floodplain has been well documented by Duguid (1976). The contamination arises from two general sources: SWDA 4, through seepage and through the stream flowing along the south boundary of this disposal area (Fig. 3); and plant effluents, when much of the area was flooded by the intermediate pond. Overflow of White Oak Creek water onto floodplain no. 2 has been greatly reduced by the installation in 1977 of a diversion channel (Fig. 14) that carries the stream flow into its original channel adjacent to SWDA 5. Due to the accumulation of debris in this vicinity, White Oak Creek had bypassed its original channel, forming a new one (with diminished capacity) across the floodplain area.

Floodplain areas nos. 3 and 4 are located to the east and to the west, respectively, of White Oak Creek above monitoring station 3 (Fig. 14). When flooding occurs in this area during intense storm events, the water on floodplain no. 3 is impounded to some extent by the elevated roadbed that leads to the bridge at the monitoring station. Strontium-90 derived from numerous upstream sources has been deposited in the soils of both floodplains. Additional potential sources of contamination in this area are the operations at the hydrofracture site and the presence of intermediate-level liquid waste transfer lines, one of which (no longer in use) crosses under White Oak Creek about 50 meters above monitoring station 3.

Surface-water samples were collected at various sites in the floodplain areas during the comprehensive sampling program carried out in December 1977; these have been analyzed for $^{90}Sr$ activity (Table 11). In addition, ground-water samples were collected from wells adjacent to the creek (Table 12). Whereas three of these were taken in December from existing wells, the remainder represent samples obtained from shallow holes produced when soil cores were taken at each White Oak Creek sampling station, on either side of the stream outside the channel. The soils were cored during February and March 1978; analyses have not yet been made. The ground waters were extracted from the holes with a hand pump. Because the holes were only about 2 ft deep, many did not intersect the ground-water table. For those which did, the sampling usually extended over a period of time (Table 12) in order to collect one liter of water for analysis.

The $^{90}Sr$ concentrations in waters from all collection sites in the vicinity of floodplain no. 1 (excluding White Oak Creek) are shown in Fig. 15. For those sites at which samples were obtained on numerous occasions, the activities represent the mean values. The data identify a rather small area of appreciable $^{90}Sr$ contamination on the east side of White Oak Creek just above the bridge at Haw Ridge. The contaminated zone does not appear to be extensive, and there is no evidence of significant activity levels on the west side of the creek in this area.

Upstream from the confluence of the northwest tributary and White Oak Creek, relatively high $^{90}Sr$ concentrations are present in the ground waters on both sides of the creek (Fig. 15). Surface-runoff water at one location, just above T-5, also has an activity level appreciably higher than background. Discharge from these sources may account to some degree for the sharp rise in $^{90}Sr$ concentration in White Oak Creek as it passes through this area (Fig. 10), although the discharge from T-5 (Sewage Treatment Plant effluent) must be the dominant source. While this contaminated floodplain must be considered as a potentially significant source of $^{90}Sr$ in White Oak Creek, it is

Table 11. Concentrations of $^{90}Sr$ (dpm/ml) in surface-water samples from White Oak Creek floodplain areas, December 1977

| Sample | Date | $^{90}Sr$ |
|---|---|---|
| WOC-1C | 12-14 | 0.74 |
| | 12-20 | 0.89 |
| | 12-28 | 1.5 |
| WOC-2A | 12-2 | 0.13 |
| | 12-5 | 0.20 |
| | 12-9 | 0.16 |
| | 12-14 | 0.13 |
| | 12-16 | 0.29 |
| | 12-20 | 0.17 |
| | 12-28 | 0.57 |
| WOC-2B | 12-14 | 0.74 |
| | 12-16 | 0.81 |
| | 12-20 | 0.57 |
| WOC-2C | 12-14 | 0.10 |
| | 12-16 | 0.33 |
| | 12-20 | 0.14 |
| WOC-2D | 12-28 | 0.12 |
| WOC-2E | 12-28 | 0.01 |
| WOC-3A | 12-14 | 0.10 |
| | 12-20 | 0.09 |
| WOC-3B | 12-28 | 0.28 |
| WOC-8B | 12-14 | 0.90 |
| | 12-16 | 0.32 |
| | 12-20 | 0.23 |
| | 12-28 | 0.41 |
| T-2A | 12-20 | 12.2 |
| | 12-28 | 6.8 |

Table 12. Concentrations of $^{90}Sr$ (dpm/ml) in ground-water samples from White Oak Creek Floodplain areas

| Sample | Date | $^{90}Sr$ |
|---|---|---|
| Well B | 12/30/77 | 5.7 |
| E60/S150 | 12/30/77 | 1.5 |
| W7.7/S295.7 | 12/29/77 | 1.2 |
| GW-WOC-1E | 2/13/78-3/10/78 | 3.0 |
| GW-WOC-1W | 2/07/78-3/08/78 | 0.27 |
| GW-WOC-2E | 2/07/78-2/15/78 | 2.3 |
| GW-WOC-2W | 2/07/78-2/15/78 | 6.5 |
| GW-WOC-8W | 2/27/78 | 0.05 |
| GW-WOC-9E | 2/27/78-3/03/78 | 0.06 |
| GW-WOC-10E | 3/03/78 | 0.45 |
| GW-WOC-10W | 3/03/78 | 0.72 |
| GW-WOC-11E | 3/06/78-3/07/78 | 0.02 |
| GW-WOC-11W | 3/06/78-3/08/78 | 0.42 |

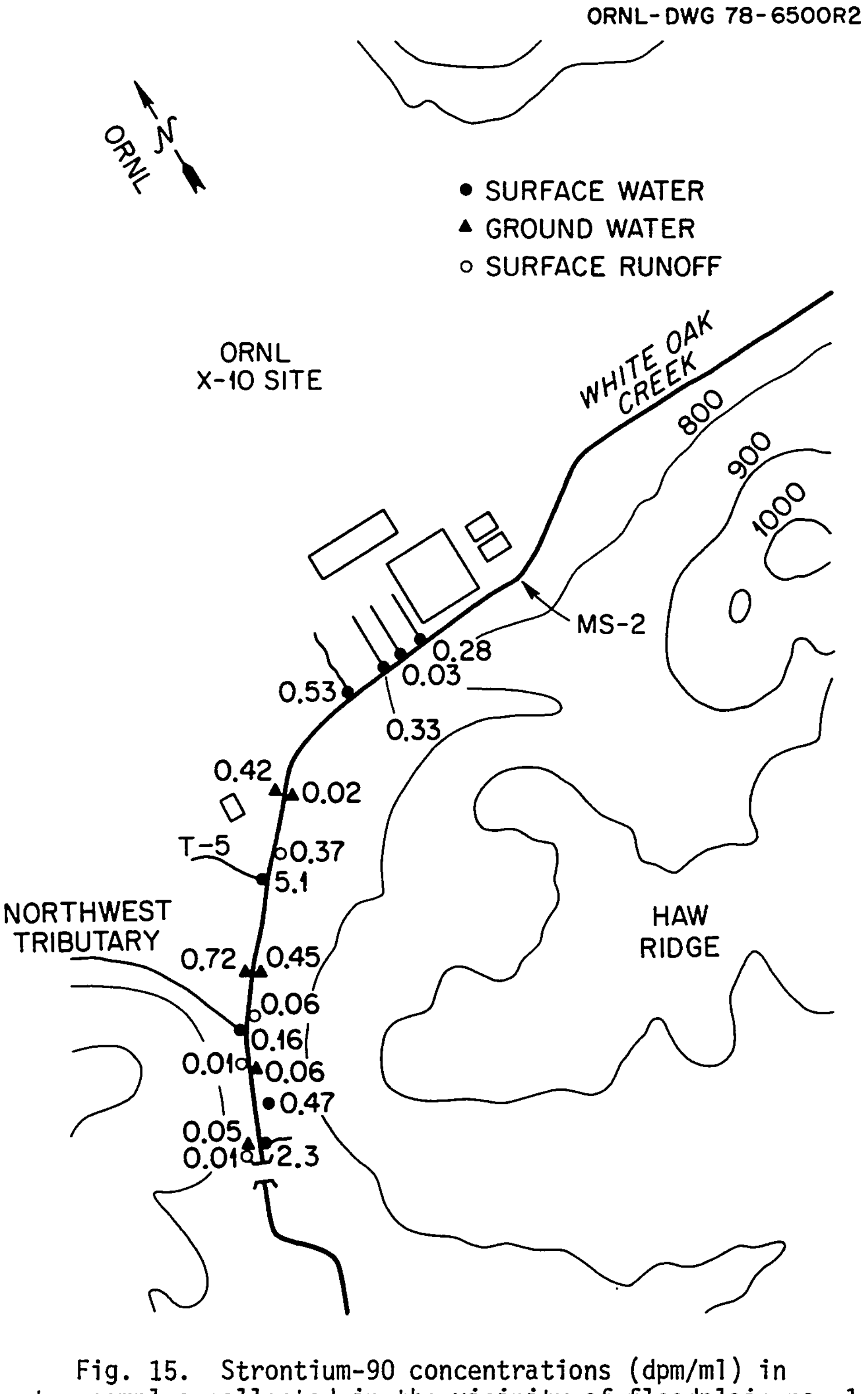


Fig. 15. Strontium-90 concentrations (dpm/ml) in water samples collected in the vicinity of floodplain no. 1.

impossible to quantify its actual contribution in an adequate manner at this time.

The $^{90}Sr$ concentrations in waters from all collection sites in floodplains 2, 3, and 4 are presented in Fig. 16. Where samples were obtained on more than one occasion, the mean activity level is shown. The data identify an area of $^{90}Sr$ contamination just above monitoring station 3, between White Oak Creek profile stations WOC-1 and WOC-2. In floodplain no 3, to the east of White Oak Creek, the surface water samples show a progressive increase in $^{90}Sr$ activity toward monitoring station 3. This surface drainage is eventually discharged to White Oak Creek through tributaries WOC-1A and WOC-1B (Fig. 9). Ground-water activity levels indicate that the soils are contaminated with $^{90}Sr$ on both sides of the creek in this area. Undoubtedly the contamination is the result of flooding by White Oak Creek water during intense storm events. Although the discharge of $^{90}Sr$ from these contaminated surface- and ground-water sources to White Oak Creek cannot be quantified, there are no observable effects on the $^{90}Sr$ concentration profile in the creek as it flows through the area (Fig. 10).

The presence of an intermediate-level liquid waste transfer line, which is no longer in use, provides another possible contamination source. The $^{90}Sr$ activity in Well B (Figs. 14 and 16) is probably related to a leak in the transfer line that occurred on the slope just above the well (Duguid and Sealand 1975). Well B was installed to monitor the radioactivity level in ground water produced by the contaminated area around the leak. After removal of contaminated soil from the vicinity of the leak during July and August 1973, Duguid and Sealand found that the $^{90}Sr$ concentration in ground water from Well B dropped from 1.35 to 0.28 dpm/ml in a six-week period of time (August 27-October 5). The $^{90}Sr$ activity of 5.7 dpm/ml found in ground water from Well B on December 30, 1977, suggests that contamination from the transfer line leak may still present a problem. Contaminated soil that was eroded and transported away from the vicinity of the leak remains in the area.

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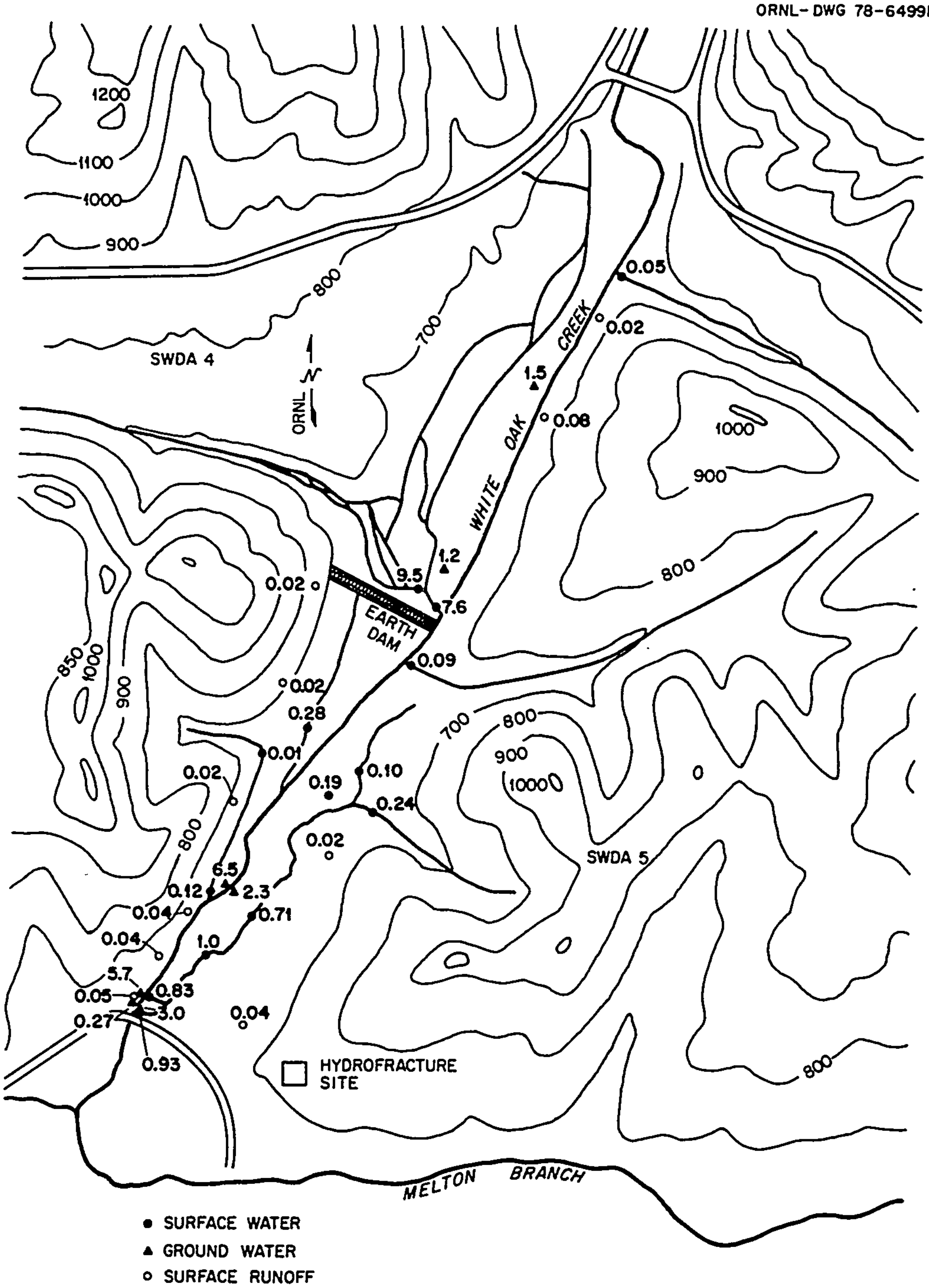


Fig. 16. Strontium-90 concentrations (dpm/ml) in water samples collected in floodplains 2, 3, and 4.

Two ground-water analyses from floodplain no. 2, located between SWDA 4 and White Oak Creek, are shown in Fig. 16. The $^{90}Sr$ concentrations are as low as or lower than values reported previously by Duguid (1975, 1976) for water samples from these wells. Higher activity levels were found by Duguid in water samples from wells west of the former creek channel. Discharge of $^{90}Sr$ from this area of the floodplain to White Oak Creek may occur through the movement of ground water into the former creek channel, where it joins surface-runoff water that eventually enters the present channel near the earth dam.

Previous studies (Duguid, 1975, 1976) have emphasized contaminated floodplain no. 2, adjacent to SWDA 4, as a source of $^{90}Sr$ discharge to White Oak Creek. It is now evident that three additional floodplain areas must be similarly regarded. However, the significance of the $^{90}Sr$ contributions from any or all of these sources is uncertain in view of the problems associated with quantification of their discharges.

## Streamflow Measurements

Streamflow data are collected continuously at monitoring stations 2 and 3 by the Operations Division; total volumes are reported on a monthly basis. Streamflow or stream discharge data at intermediate points along White Oak Creek can be used to estimate the total $^{90}Sr$ contributions in a given period of time from identifiable sources between the two monitoring stations and thus to assess the relative importance of each. Therefore streamflow measurements were made throughout the study reach with a vertical-axis current meter using the midsection method of measurement (Buchanan and Somers 1969). Streamflow measurements made in this manner are subject to several possible sources of error (Carter and Anderson, 1963), most of which are associated with velocity measurement. On several occasions, velocity was near the minimum which could be measured accurately with the current meter. Although some measurements obviously contain more error than others, it seems reasonable to assume a 5% average for our data.

Measurements were made at each of the sampling sites WOC-2 through WOC-14, with the exception of WOC-8, where a large gravel bar divides the flow. Additionally, flow in the northwest tributary (T-4, Fig. 9) which drains the area containing SWDA 3 (Fig. 1) was also measured. A total of 13 individual measurements constitutes a complete streamflow profile (Table 13).

In order to minimize temporal variations during any given stream-discharge profile, all flow measurements were normalized to the flow at monitoring station 3, which is recorded at 15-min intervals by the U.S. Geological Survey. Each measured flow value was divided by the flow at station 3 recorded at a slightly later time, as determined by the estimated travel time between station 3 and the upstream profile site. Thus, a normalized flow value (Table 13) represents a fractional part of the flow at monitoring station 3.

Three streamflow profiles were measured in conjunction with this study. The first was made on December 20, 1977, when flow averaged 8.95 cfs (0.253 $m^3$/sec) at monitoring station 3; measurements were not taken at all sites in the study reach. When the need for more complete and more accurate data became evident, two additional profiles were measured on March 7 and March 16-17, 1978; flow at station 3 averaged 10.7 cfs (0.303 $m^3$/sec) and 15.4 cfs (0.436 $m^3$/sec) respectively on these dates. Because all flow data are normalized to the flow at monitoring station 3, we believe that the relative flow values at the various sites are valid for most periods of time. Based upon this premise, four additional flow measurements, collected in conjunction with another investigation, were also incorporated to increase the sample size. Data for profile 3 were taken with greater accuracy, achieved by taking a greater number of velocity readings, and for longer periods of time, across each measuring section. This profile exhibits the most consistent variation of flow with channel distance when viewed in terms of tributary junctions and monitoring station 3 data.

Measured streamflow ($m^3$/sec) and normalized flow values for profile 3, as well as the mean normalized values for all measurements, are given in Table 13. Figure 17 illustrates the longitudinal variation of normalized streamflow (profile 3), normalized $^{90}Sr$ concentration, and

Table 13. Measured and normalized stream discharge values for White Oak Creek between monitoring stations 2 and 3

| Station | Profile 3 measured discharge ($m^3$/sec) | Profile 3 normalized discharge | Mean normalized discharge |
|---|---|---|---|
| WOC-2 | 0.493 | 1.036 | 0.996 |
| WOC-3 | 0.459 | 0.964 | 0.898 |
| WOC-4 | 0.473 | 0.994 | 1.006 |
| WOC-5 | 0.473 | 0.994 | 0.981 |
| WOC-6 | 0.419 | 0.881 | 0.874 |
| WOC-7 | 0.419 | 0.881 | 0.832 |
| WOC-9 | 0.328 | 0.690 | 0.726 |
| T-4 | 0.102 | 0.215 | 0.201 |
| WOC-10 | 0.292 | 0.632 | 0.636 |
| WOC-11 | 0.242 | 0.578 | 0.595 |
| WOC-12 | 0.226 | 0.539 | 0.568 |
| WOC-13 | 0.213 | 0.509 | 0.516 |
| WOC-14 | 0.215 | 0.514 | 0.516 |

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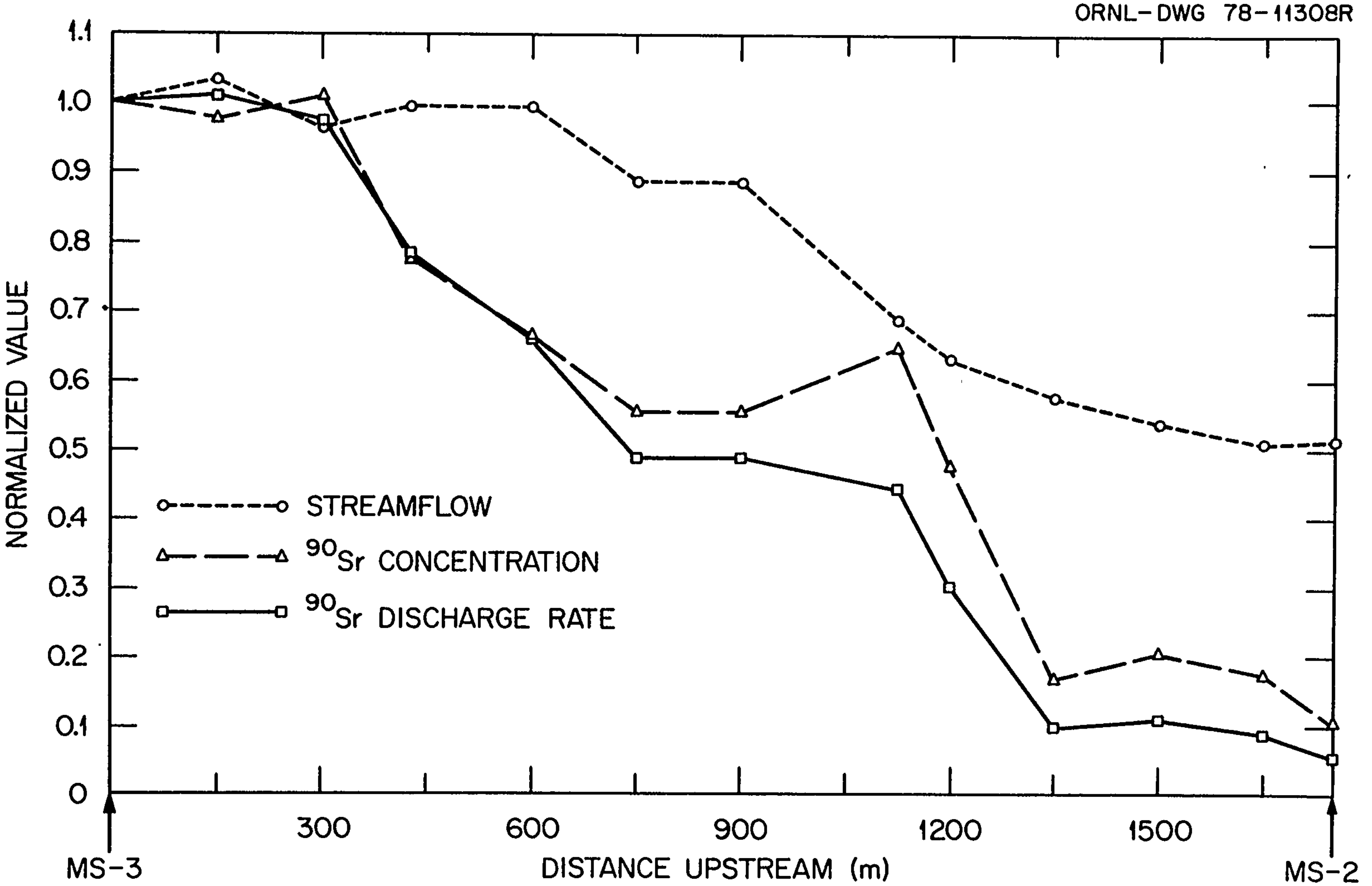


Fig. 17. Normalized longitudinal profiles of streamflow, $^{90}Sr$ activity, and $^{90}Sr$ discharge rate for the study reach of White Oak Creek.

normalized $^{90}Sr$ discharge rate throughout the study reach of White Oak Creek. The normalized $^{90}Sr$ concentration profile is based upon the data from the five normal concentration profiles, the average concentration at each sampling site having been divided by the average $^{90}Sr$ concentration at station WOC-1. Each data point on the curve showing the normalized $^{90}Sr$ discharge rate represents the product of normalized streamflow and normalized $^{90}Sr$ concentration. These curves are valid only under normal conditions in the study reach of the creek; during an intermittent release from Waste Ponds 3539 and 3540 the situation would be altered. A nearly identical pattern of variation is exhibited in the $^{90}Sr$ concentration and discharge-rate profiles. The slight decreases in $^{90}Sr$ discharge rate between stations WOC-12 and WOC-11 and between WOC-3 and WOC-2 are due to analytical uncertainties and do not represent the actual situation.

The normalized profiles in Fig. 17 illustrate the longitudinal mixing pattern and the distance lag between the point of $^{90}Sr$ input and the point of elevated concentration within the creek itself. For example, contaminated effluent from the Sewage Treatment Plant enters White Oak Creek about midway between WOC-11 and WOC-10 (1275 m upstream); however, the rise in the $^{90}Sr$ concentration profile is not complete until station WOC-9 is reached. This condition has been verified by field observation. Water discharging from this tributary (T-5) is often of different color and turbidity than creek water. Mixing of these waters was observed to be incomplete until the flow in White Oak Creek reached a point below the confluence with the northwest tributary (Fig. 9). Similarly, water carrying $^{90}Sr$ from SWDA 4 that discharges through tributary T-2 is not mixed thoroughly with the creek water until station WOC-3 is reached. This trend was verified by detailed water sampling between stations WOC-4 and WOC-3, to be described in the following section.

# STRONTIUM-90 DISCHARGE TO WHITE OAK CREEK BETWEEN MONITORING STATIONS 2 AND 3 DURING DECEMBER 1977

In order to assess properly the relative importance of the various sources which contribute $^{90}Sr$ to White Oak Creek in the reach between monitoring stations 2 and 3, it is necessary to quantify the $^{90}Sr$ discharge from each source through the use of some sort of monitoring system. Tributaries could be monitored by setting up a hydraulic device such as a weir or a Parshall flume, along with a proportional sample collector. Because the important sources of $^{90}Sr$ discharge other than SWDA 4 were initially unidentified, such elaborate experiments were not included in this study. Nevertheless it is possible at present to estimate the relative importance of certain $^{90}Sr$ sources through the use of Operations Division flow data for plant effluents and the White Oak Creek flow measurements that were taken during this study.

On the basis of the longitudinal profiles of $^{90}Sr$ concentration in White Oak Creek (Fig. 10), four major sources of $^{90}Sr$ discharge to the creek in the study reach have been identified: Waste Ponds 3539 and 3540, the Sewage Treatment Plant, the northwest tributary, and SWDA 4. The $^{90}Sr$ entering the study reach is recorded at monitoring station 2, and the discharge from the Process Waste Treatment Plant is recorded at monitoring station 1. Direct surface runoff during storm events and discharge from contaminated floodplain areas through direct runoff and ground-water flow, though unmonitored, appear to be minor sources of $^{90}Sr$ input to White Oak Creek.

## Waste Ponds 3539 and 3540

Waste Ponds 3539 and 3540 receive liquid waste from the Building 4500 complex. The flow of liquid to these ponds is monitored by the Operations Division; flow for December 1977 is given in Table 14. Because of the intermittent nature of the discharge from these waste ponds, and also because they were not initially considered as a source of $^{90}Sr$, the effluent was not included in the course of profile

Table 14. Strontium-90 discharge from sources in the White Oak Creek study reach, December, 1977, and the relative importance of each. The percent contribution is based on the net $^{90}Sr$ discharge between monitoring stations 2 and 3 for the month.

| Source | Flow ($10^6$ gal.) | $^{90}Sr$ (dpm/ml) | $^{90}Sr$ discharge (Ci) | Relative contribution (%) |
|---|---|---|---|---|
| Monitoring Station No. 2 | 176.15 | 0.05 (0.04) | 0.015 (0.012) | |
| Waste Ponds 3539 and 3540 | 5.012 | 6.0 | 0.051 | 24.1 |
| Process Waste Treatment Plant (Monitoring Station No. 1) | 4.30 | 0.14 | 0.001 | 0.5 |
| Sewage Treatment Plant | 8.246 | 5.14 | 0.072 | 34.0 |
| Northwest tributary | 58.252 | 0.16 | 0.016 | 7.5 |
| | | | 0.155 | |
| Monitoring Station No. 3 | 289.81 | 0.46 (0.40) | 0.227 (0.197) | |
| SWDA 4 | -- | -- | 0.072 | 34.0 |

sampling during the December study. Thus, the only $^{90}Sr$ activity analysis available for this liquid waste is the value of 6.0 dpm/ml obtained December 2 on a grab sample taken from Waste Pond 3540. This activity level has been combined with the waste-pond flow to yield a rather tenuous estimate of the $^{90}Sr$ discharge from this source for the month (Table 14). However, an indication of the representative nature of the $^{90}Sr$ concentration used in this calculation is given by the analysis (4.6 dpm/ml) of a flow-proportional sample of the liquid discharged to these ponds during March 1978 (L. Lasher, personal communication). The corresponding $^{90}Sr$ discharge to White Oak Creek (0.044 Ci) is comparable to the value calculated for December 1977 (0.051 Ci).

Sewage Treatment Plant

Effluent from the Sewage Treatment Plant enters White Oak Creek through tributary T-5 (Fig. 9). Surface drainage comprises an unknown proportion of the discharge in this tributary, which was sampled regularly at its confluence with White Oak Creek during December 1977. In order to investigate the relationship between the activity levels found in this tributary (Table 7) and the plant effluent, water samples were collected on December 28 at several locations above the tributary's confluence with White Oak Creek. The $^{90}Sr$ concentrations (Fig. 18) indicate that the activity is in fact in the plant effluent, and that on this occasion the surface drainage had no observable dilutive effect. Significant dilution probably occurs only during and immediately after storm events.

The $^{90}Sr$ discharge to White Oak Creek from the Sewage Treatment Plant (Table 14) was calculated by combining the December flow through this facility with the mean value for the $^{90}Sr$ analyses of seven T-5 water samples. The $^{90}Sr$ activity used is thought to be fairly representative of the December plant effluent, as the individual analyses (Table 7) are not highly variable. The analysis of a flow-proportional sample of the effluent would, of course, have been preferable.

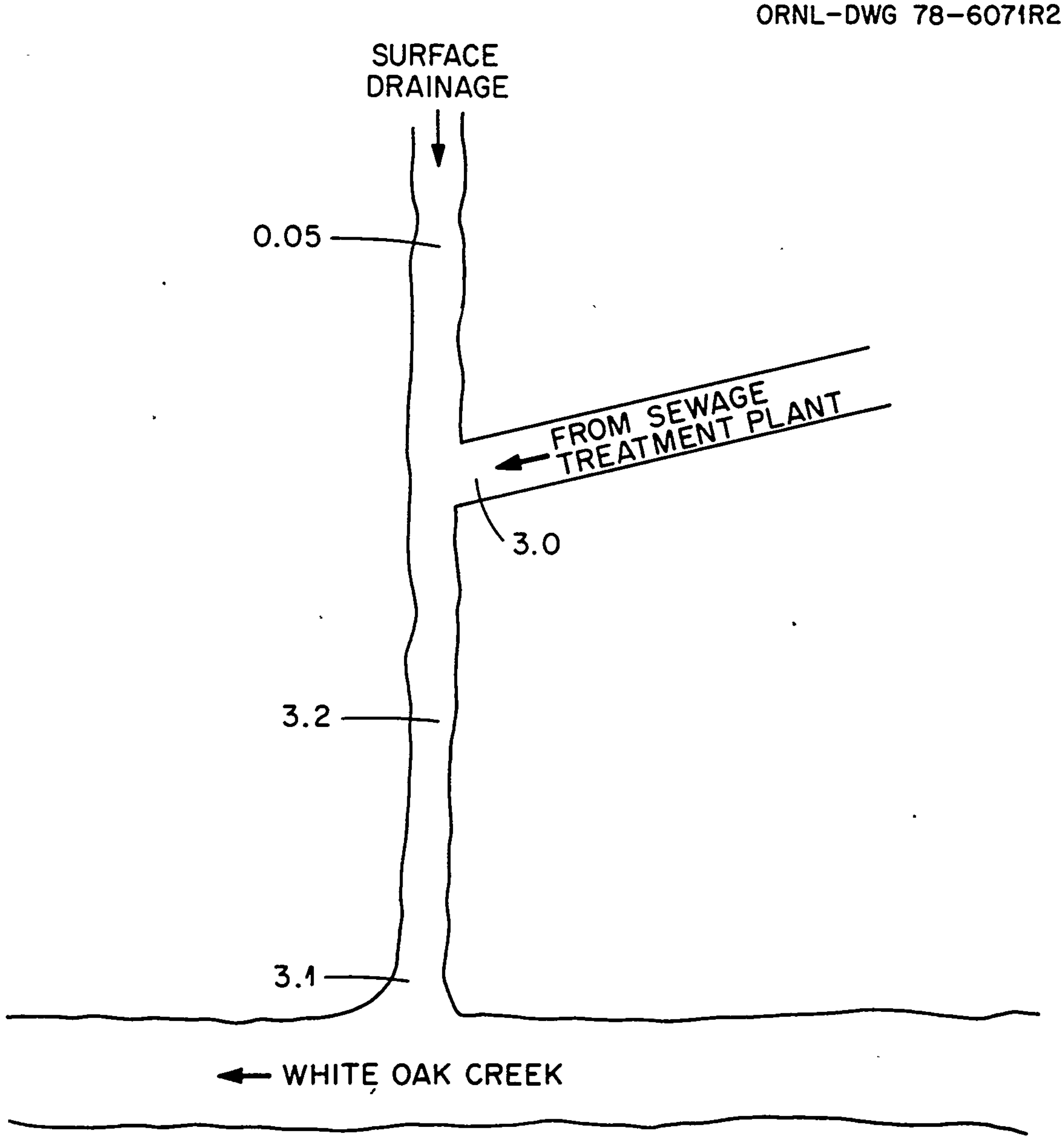


Fig. 18. Strontium-90 concentrations (dpm/ml) in water samples from tributary T-5, December 28, 1977.

Northwest Tributary

The northwest tributary to White Oak Creek is the largest tributary in the study reach; its discharge is roughly one-third as great as the discharge of White Oak Creek just above the point of confluence (Table 13, T-4). The December 1977 flow in this tributary (Table 14) has been obtained by multiplying the White Oak Creek flow at monitoring station 3 by 0.201, the ratio between the discharge in the northwest tributary obtained by stream gaging measurements (Table 13) and the discharge at monitoring station 3. Whereas the $^{90}Sr$ concentration in this tributary is relatively low and the effect is to reduce the ambient activity level in White Oak Creek (Fig. 10), the $^{90}Sr$ discharge to the creek is nevertheless significant (Table 14).

The probable source of the bulk of the $^{90}Sr$ in the northwest tributary is SWDA 3, located near the stream's headwaters (Fig. 1). The release of radionuclides from SWDA 3 has not been monitored since November 1973 when Duguid (1975) collected ground-water samples from 12 wells in the immediate vicinity of the disposal area. Analyses revealed $^{90}Sr$ activity in six of the samples; the highest concentration was 3.3 dpm/ml. In addition to the seven $^{90}Sr$ analyses of northwest tributary waters obtained during the December 1977 phase of the present study, samples were taken on 13 occasions during October 1977 at a point approximately 90 m upstream from the confluence with White Oak Creek. Strontium-90 analyses of these samples (Table 4) show a mean activity level of 0.28 dpm/ml, considerably higher than the mean of 0.16 dpm/ml for the December water samples. The difference probably reflects the dilutive effect of a tributary that enters the northwest tributary between the two sampling points.

During each of the past two summers, D. A. Webster (personal communication) has sampled water pools in the northwest tributary channel at a location approximately 750 m upstream from the confluence with White Oak Creek. When the samples were taken, the stream was not flowing at or above this location. In July 1976 the pooled water had a $^{90}Sr$ concentration of 15.8 dpm/ml; in August 1977 the activity was 18.3 dpm/ml. Although there may have been a degree of concentration due to evaporation, the results probably reflect the local ground-water activity at these times. Thus, high $^{90}Sr$ concentrations may be present in ground waters at considerable distances from SWDA 3.

The northwest tributary is clearly a significant source of the $^{90}Sr$ present in White Oak Creek (Table 14). There is sufficient evidence to indicate that a comprehensive inspection of radionuclide release from SWDA 3 should be carried out.

SWDA 4

Strontium-90 from SWDA 4 is discharged via the stream that lies to the south of this disposal area (Fig. 3); it enters White Oak Creek through tributary T-2, a former channel of the creek (Fig. 9). Any $^{90}Sr$ discharged by ground-water movement from the eastern portion of SWDA 4 or from the adjacent contaminated floodplain area enters the former creek channel and also reaches White Oak Creek at T-2. When the discharge of the stream south of SWDA 4 flows into the former creek channel, a ponding effect occurs as the water backs up into the channel. Thus the flow from T-2 into White Oak Creek is imperceptible except during and after intense storm events when surface-runoff water flows down the former creek channel. Attempts to gage the discharge of T-2 were unsuccessful.

In spite of the very low flow from T-2 into White Oak Creek, the high $^{90}Sr$ activity level in the discharge (Table 7) does produce a significant increase in the $^{90}Sr$ concentration of creek water (Fig. 10). In the absence of flow data for T-2, perhaps the best estimate of the $^{90}Sr$ discharged from SWDA 4 to White Oak Creek in December 1977 is obtained by subtracting the sum of the $^{90}Sr$ discharges from other sources in the study reach from the total $^{90}Sr$ discharged at monitoring station 3 during the month (Table 14). This estimate should be regarded as an upper limit in view of the unmonitored contributions from other potential sources, primarily the contaminated floodplain areas.

The $^{90}Sr$ discharges at monitoring stations 2 and 3 for December 1977 (Table 14) are based upon Operations Division flow data and the mean $^{90}Sr$ concentrations for water samples collected at these two locations during the course of the December sampling profiles (Table 7, WOC-14 and WOC-1). Although the Operations Division $^{90}Sr$ concentrations and discharges (shown in parentheses in Table 14) have been determined from flow-proportional water samples collected at the monitoring stations and are therefore more representative for the month, it is felt that values determined from the profile samples are more internally consistent with the other data reported in Table 14.

The $^{90}Sr$ discharge from SWDA 4 can also be estimated from the increase in $^{90}Sr$ activity in White Oak Creek as it passes tributary T-2, and from the creek flow in this interval for December, 1977. In order to determine what proportion of the activity increase in this creek interval can be attributed to the discharge from T-2, it is necessary to determine the distance downstream from the confluence between T-2 and White Oak Creek at which mixing of their waters is complete. During the course of profile sampling on December 28, 1977, water samples were collected at 30-m intervals between stations WOC-3 and WOC-4, the two stations immediately downstream from the point of confluence (Fig. 9). The $^{90}Sr$ activities presented in Fig. 19 show that complete mixing is achieved below station WOC-4. Therefore, the total effect of T-2 discharge on the $^{90}Sr$ concentration in White Oak Creek water can be obtained by comparing the activity levels at stations WOC-3 and WOC-5 for each of the seven longitudinal concentration profiles. Thus, the average increase in $^{90}Sr$ concentration in White Oak Creek water produced by T-2 discharge during December is 0.18 dpm/ml.

White Oak Creek flow does not change between stations WOC-5 and WOC-3, within the uncertainties in the stream-gaging measurements (Table 13). By using the average of the Profile 3 normalized discharge values at these two stations and the flow at monitoring station 3 for December 1977 (Table 14), an estimate of the creek flow at the two stations during the month can be calculated. When this flow is combined with the average increase in $^{90}Sr$ activity between stations WOC-5 and WOC-3, an estimated $^{90}Sr$ discharge of 0.088 Ci is obtained for SWDA 4

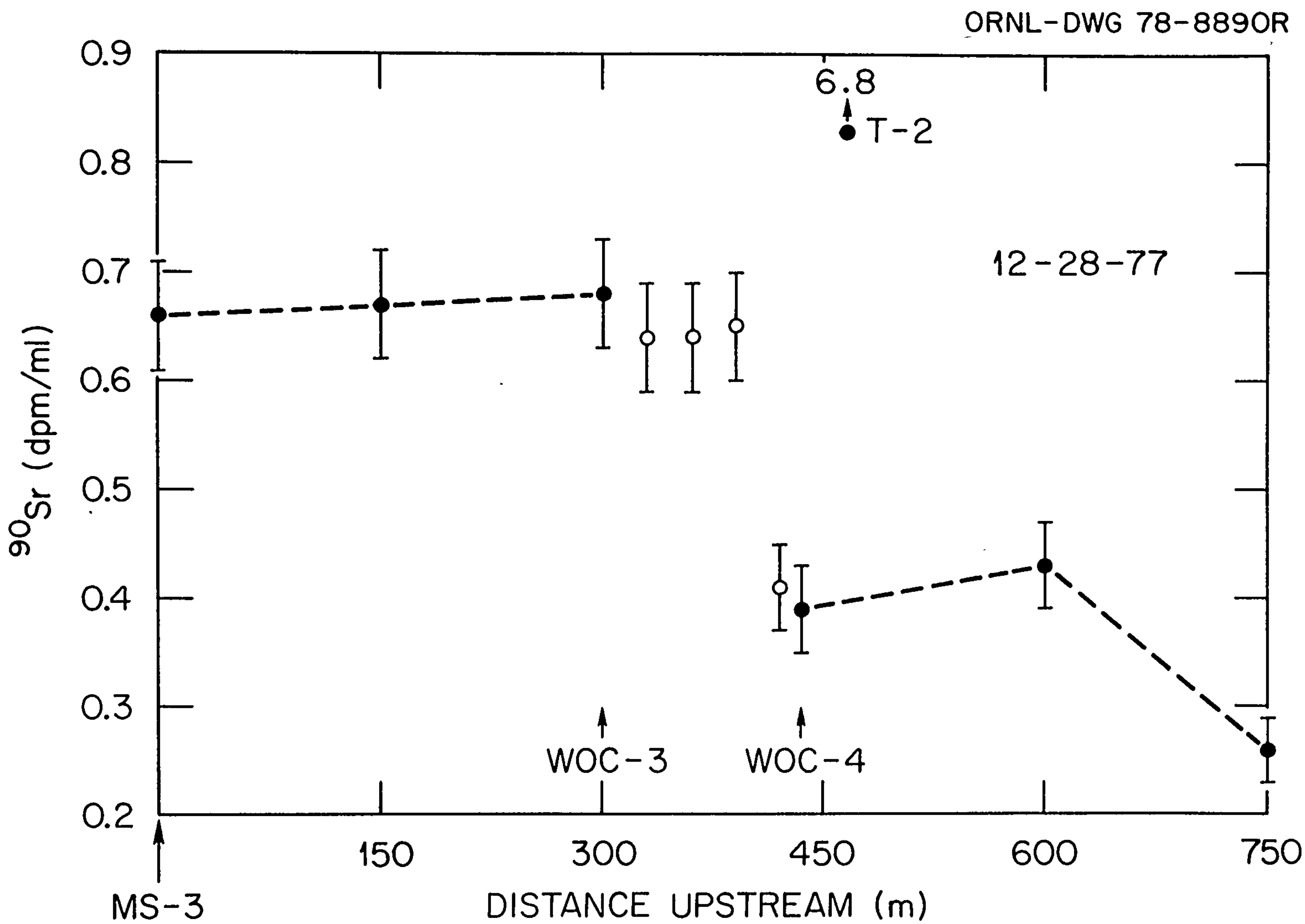


Fig. 19. Strontium-90 concentrations in White Oak Creek in the vicinity of stations WOC-3 and WOC-5, December 28, 1977.

during December. This value is roughly comparable to the more reliable estimate of 0.072 Ci derived previously (Table 14). An estimate can also be obtained from the yearly values (Table 3) calculated by the method of Duguid (1975). Thus, for water years 1973-1977, the average monthly $^{90}Sr$ discharge from SWDA 4 is 0.10 Ci.

The relative importance of each major source that discharges $^{90}Sr$ to the study reach of White Oak Creek is evaluated in Table 14. The percent contributions have been determined by comparison with the net $^{90}Sr$ input between monitoring stations 2 and 3 during December 1977. It is clear that there are two additional $^{90}Sr$ sources within the study reach, the Waste Ponds and the Sewage Treatment Plant, which are comparable in importance to SWDA 4. Therefore, the practice of assigning the increment in White Oak Creek $^{90}Sr$ discharge between monitoring stations 2 and 3 to discharge from SWDA 4 is incorrect. These observations have been made possible in large part by the vast reduction in $^{90}Sr$ discharged from the Process Waste Treatment Plant since the new plant became operational in April 1976. It is entirely possible that the relatively high $^{90}Sr$ discharges recorded at monitoring station 3 in recent years, which prompted the present investigation, were due to elevated $^{90}Sr$ activity levels in the effluent from either the Waste Ponds or the Sewage Treatment Plant, or both.

## STRONTIUM-90 DISCHARGE TO WHITE OAK CREEK BETWEEN MONITORING STATIONS 2 AND 3 DURING APRIL 1978

The identification of Waste Ponds 3539 and 3540 as important intermittent sources of $^{90}Sr$ discharge to the study reach of White Oak Creek was not made before the completion of the December 1977 sampling program. Complete $^{90}Sr$ analytical data were not available until March 1978. Thus, when it became obvious that a thorough sampling of the effluent from the Waste Ponds would be necessary for a more complete evaluation of this $^{90}Sr$ source, it was decided to obtain samples from the ponds on a daily basis during April 1978. Strontium-90 analyses of weekly composites are presented in Table 15.

Table 15. Strontium-90 concentrations (dpm/ml) in water samples from Waste Ponds 3539 and 3540 and from the Sewage Treatment Plant, April 1978

| Composite sample | Waste Ponds 3539 and 3540 | Sewage Treatment Plant |
|---|---|---|
| 4/03 - 4/07 | 3.0 | 1.4 |
| 4/10 - 4/14 | 3.2 | 1.1 |
| 4/17 - 4/21 | 0.80 | 1.1 |
| 4/24 - 4/28 | 0.10 | 1.1 |

The Operations Division also began to collect, on a monthly basis, a flow-proportional sample of the liquid waste before it entered the ponds.

The $^{90}Sr$ activity in the Waste Ponds shows a marked decline during the last two weeks of April (Table 15). This is undoubtedly the result of a corrective measure taken by the Operations Division; a portion of the liquid waste normally routed to the Waste Ponds was diverted to the Process Waste Treatment Plant, beginning on April 17, 1978 (L. Lasher, personal communication, ORNL). If the $^{90}Sr$ activity in the effluent from the ponds remains at the level recorded during the last week of April, this source will become insignificant as a contributor of $^{90}Sr$ to White Oak Creek.

The Sewage Treatment Plant effluent was also sampled on a daily basis during April 1978, at the point of discharge from the plant itself. This was done in order to obtain more representative data for this source, and to avoid any effects of surface drainage that might have occurred in the tributary which had been sampled during the December 1977 study. The $^{90}Sr$ concentrations in weekly composites of the plant effluent are given in Table 15. The activity level is quite uniform throughout the month, but significantly lower than that recorded during December 1977 (Table 14 and Fig. 18). The reduction occurred even though no corrective measures had been taken; it is clear that the $^{90}Sr$ contamination in the effluent from this source can vary considerably over periods of months.

The $^{90}Sr$ discharged from each of these sources to White Oak Creek during April 1978 has been calculated through the use of Operations Division flow data (Table 16). In the case of the Sewage Treatment Plant the calculation was made on a weekly basis using the $^{90}Sr$ concentrations in Table 15. For the Waste Ponds, the $^{90}Sr$ activity in the flow-proportional sample collected by the Operations Division was employed. The $^{90}Sr$ discharged at monitoring stations 1, 2, and 3 (Table 16) was determined from Operations Division data. Discharge of $^{90}Sr$ from the northwest tributary was estimated by combining the mean $^{90}Sr$ activity for this tributary in December 1977

Table 16. Strontium-90 discharge from sources in the White Oak Creek study area, April, 1978, and relative importance of each. The percent contribution is based on the net $^{90}Sr$ discharge between monitoring stations 2 and 3 for the month.

| Source | Flow ($10^6$ gal.) | $^{90}Sr$ (dpm/ml) | $^{90}Sr$ discharge (Ci) | Relative contribution (%) |
|---|---|---|---|---|
| Monitoring Station No. 2 | 117.758 | 0.06 | 0.012 | |
| Waste Ponds 3539 and 3540 | 6.448 | 1.5 | 0.016 | 9.4 |
| Process Waste Treatment Plant (Monitoring Station No. 1) | 2.914 | 5.4 | 0.027 | 15.8 |
| Sewage Treatment Plant | 6.152 | 1.2 | 0.012 | 7.0 |
| Northwest tributary | 51.392 | (0.16)[a] | (0.014) | 8.2 |
| | | (Total) | 0.081 | |
| Monitoring Station No. 3. | 255.68 | 0.42 | 0.183 | |
| SWDA 4 | -- | -- | 0.102 | 59.6 |

[a]Numbers in parentheses are estimates based on $^{90}Sr$ concentrations from December 1977.

with a flow value obtained by multiplying the White Oak Creek flow at monitoring station 3 during April 1978 by the factor 0.201. An upper limit for the $^{90}Sr$ discharged from SWDA 4 to White Oak Creek was estimated by subtracting the sum of the $^{90}Sr$ discharges from other sources in the study reach from the total $^{90}Sr$ discharged at monitoring station 3 during the month (Table 16). This estimated $^{90}Sr$ discharge must be considered more uncertain than that obtained in December 1977 because of the uncertainty in the $^{90}Sr$ discharge from the northwest tributary for April 1978.

The relative importance of each $^{90}Sr$ source discharging to the study reach of White Oak Creek is given in Table 16. The percent contributions are based on the net $^{90}Sr$ discharge between monitoring stations 2 and 3 during April 1978. Significant changes in the relative importance of each source are observed when the April 1978 figures are compared with those for December 1977 (Table 14). The relative contribution of Waste Ponds 3539 and 3540 was reduced from 24.1% to 9.4% due to the corrective measure implemented by the Operations Division. Because this adjustment occurred midway through April, further reductions in the monthly $^{90}Sr$ discharge from the Waste Ponds can be anticipated for the future.

The Process Waste Treatment Plant showed a large increase in $^{90}Sr$ discharge to White Oak Creek during April and in relative contribution for the month (Table 16). An internal problem is responsible for this situation; corrective measures should return the input from this source to the insignificant level recorded in December, 1977.

The discharge of $^{90}Sr$ from the Sewage Treatment Plant declined sharply in April 1978 (Table 16) as compared to December 1977 (Table 14). The reduction was due primarily to the decreased $^{90}Sr$ activity in the effluent, but also to a lower effluent flow for the month. The relative contribution of $^{90}Sr$ from this source to the study reach of White Oak Creek was reduced to 7.0% (Table 16), in spite of the fact that no corrective measures were taken.

The magnitude of the apparent $^{90}Sr$ discharge from SWDA 4 to White Oak Creek in April 1978 (Table 16) increased by about 42% when compared with the estimate for December 1977 (Table 14). The relative contribution from this source increased from 34 to about 60%, due in part to the reduced $^{90}Sr$ inputs from the Waste Ponds and the Sewage Treatment Plant during April. Further increases in the relative importance of SWDA 4 and of the northwest tributary can be expected with the anticipated future reductions in $^{90}Sr$ discharges from the Waste Ponds and from the Process Waste Treatment Plant.

This comparison of $^{90}Sr$ discharge from sources in the study reach of White Oak Creek during December 1977 and during April 1978 has clarified to some extent the problems which must be overcome. The Sewage Treatment Plant is a $^{90}Sr$ source of variable and apparently unpredictable importance. Significant reduction in $^{90}Sr$ discharge from plant sources, as illustrated by the waste ponds, can be accomplished fairly rapidly. However, problems may recur in plant effluents thought to be under control, as in the case of the Process Waste Treatment Plant. Clearly, continuous monitoring of effluents from all potential plant sources is desirable. As these problems are brought under control the relative importance of SWDA 4 as a source of $^{90}Sr$ input to White Oak Creek will continue to rise. Study and solution of this problem will require major long-term efforts.

## SUMMARY AND CONCLUSIONS

The thrust of this investigation has been to analyze the causes of the substantial increase in $^{90}Sr$ discharge recorded at White Oak Creek monitoring station 3 in recent years. The analysis has focused on the identification and evaluation of sources of $^{90}Sr$ input to White Oak Creek between monitoring stations 2 and 3; these sources account for nearly all the $^{90}Sr$ released to the Clinch River at White Oak Dam. As a result of a comprehensive water-sampling program carried out in and around this reach of White Oak Creek, a number of significant observations have been made.

(1) Strontium-90 activity levels in surface and ground waters associated with SWDA 4 provide no conclusive evidence to indicate that

there is any present increase in the $^{90}Sr$ discharge from this disposal area.

(2) Prior to the implementation of corrective measures in April 1978, SWDA 4, Waste Ponds 3539 and 3540, and the Sewage Treatment Plant were the primary sources of $^{90}Sr$ discharge to White Oak Creek between monitoring stations 2 and 3. These sources were of approximately equal importance in terms of the magnitude of their contributions during December 1977.

(3) The $^{90}Sr$ discharged by the northwest tributary to White Oak Creek is not insignificant. In terms of importance in the study reach, this stream has been exceeded only by the three major sources. Sufficient evidence has been presented to warrant a thorough study of current $^{90}Sr$ release from SWDA 3.

(4) Three previously unrecognized contaminated floodplain areas adjacent to White Oak Creek have been identified. As potential sources of $^{90}Sr$ discharge to the creek, they probably represent a more serious current problem than the floodplain east of SWDA 4, because of the recent installation of the White Oak Creek diversion channel. However, the magnitude of the present $^{90}Sr$ discharge from these floodplains is probably relatively small.

(5) Direct surface runoff after storm events is not an important source of $^{90}Sr$ discharge to White Oak Creek, except possibly where the runoff crosses a contaminated floodplain and enters the creek through discrete channels. Surface drainage from the ORNL plant area can have relatively high $^{90}Sr$ activity levels, but the total discharged to the study reach of White Oak Creek does not appear to be significant.

(6) The transport of $^{90}Sr$ by suspended matter in the study reach of White Oak Creek seems to be very small compared to that which is transported in solution, primarily because of the low sorption of $^{90}Sr$ on sediments and the high concentrations of calcium and magnesium in creek water. An exception to this condition may occur if the creek has an unusually high load of suspended matter derived from the contaminated floodplains.

The results of this study suggest that the $^{90}Sr$ discharge at monitoring station 3, and therefore also at White Oak Dam, can be roughly halved by eliminating the contamination in the effluents from the Waste Ponds and the Sewage Treatment Plant. Efforts are currently being made by the Operations Division to locate the internal sources of contamination (L. Lasher, personal communication). As a result of a corrective measure implemented in April 1978, the $^{90}Sr$ discharge from the Waste Ponds has already been reduced considerably. Further significant reduction of the $^{90}Sr$ discharged to White Oak Creek from the two ORNL plant sources could be accomplished fairly rapidly.

The $^{90}Sr$ discharged from SWDA 4 via the stream that lies to the south of this disposal area should be accurately monitored by installing a weir or Parshall flume along with a flow-proportional sample collector. Such measurements would provide an accurate evaluation of the effectiveness of the surface-water diversion system installed in 1975, which seems to have been of no short-term benefit in the case of $^{90}Sr$ discharge. Discharge of $^{90}Sr$ through ground-water flow to the east from SWDA 4 and from the adjacent floodplain could be assessed by determining the $^{90}Sr$ activity in the water that flows down the former White Oak Creek channel after storm events. Most of this flow originates as runoff from Haw Ridge. If a significant amount of $^{90}Sr$ is being discharged to the present White Oak Creek channel in this way, the runoff from Haw Ridge could be diverted to White Oak Creek before it enters the former channel.

The $^{90}Sr$ discharged from the northwest tributary to White Oak Creek should also be monitored through the installation of a weir or Parshall flume. The relative significance of the input from this source will rise as the $^{90}Sr$ discharged to the creek from the two plant sources is reduced. A systematic study of the $^{90}Sr$ activity levels in surface and ground waters of the entire northwest tributary drainage basin should be carried out. The primary purpose of such a study would be to evaluate the migration of $^{90}Sr$ from SWDA 3, not only through the northwest tributary but also through the Raccoon Creek drainage to the west of SWDA 3. Any activity released through Raccoon Creek would reach the Clinch River without being detected by the ORNL monitoring system.

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# APPENDIX A

Longitudinal profiles of $^{90}Sr$ activity in White Oak Creek between monitoring stations 2 and 3, December 1977

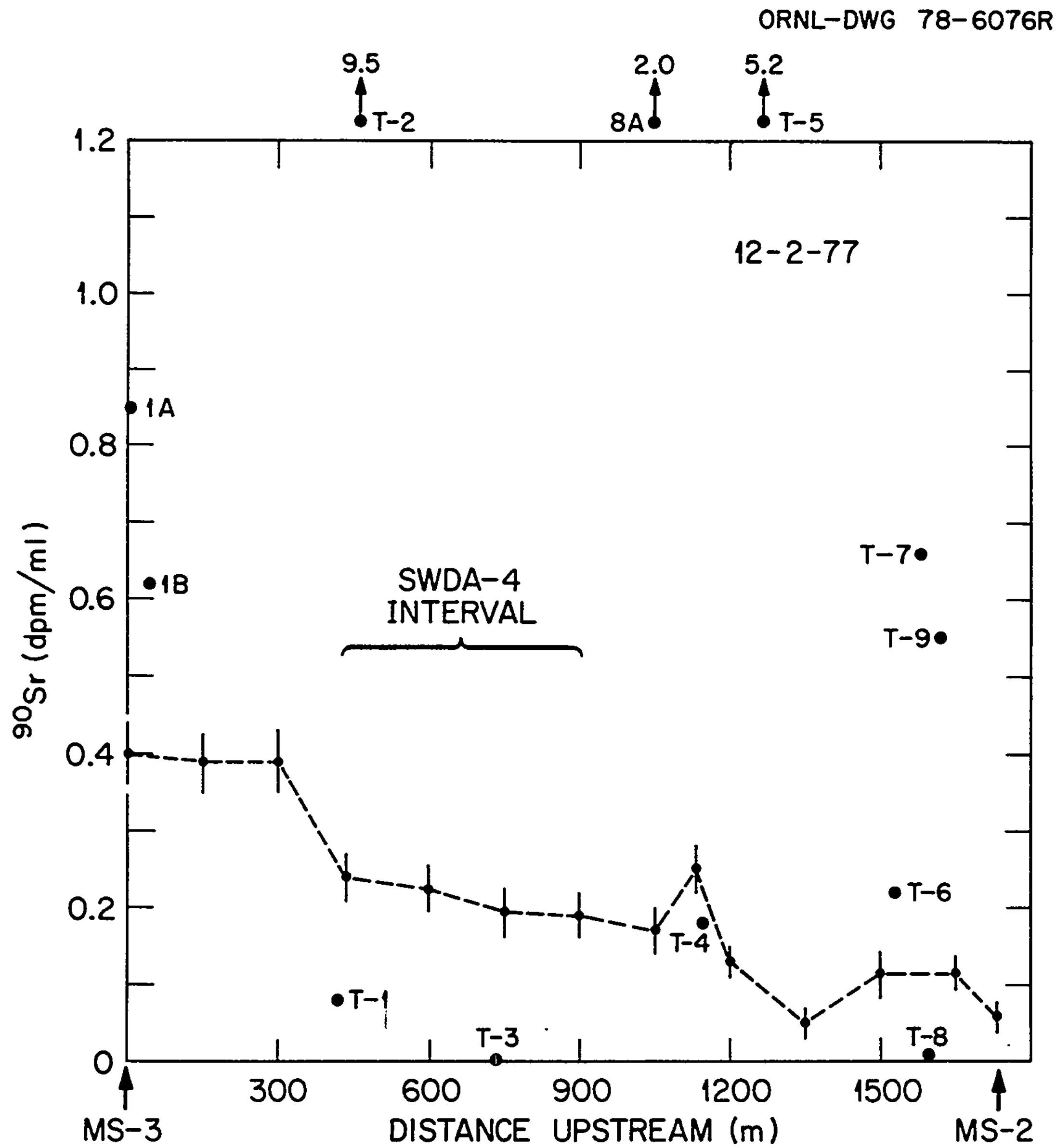


Fig. A-1. Longitudinal profile of $^{90}$Sr activity in White Oak Creek, December 2, 1977.

ORNL-DWG 78-6080R

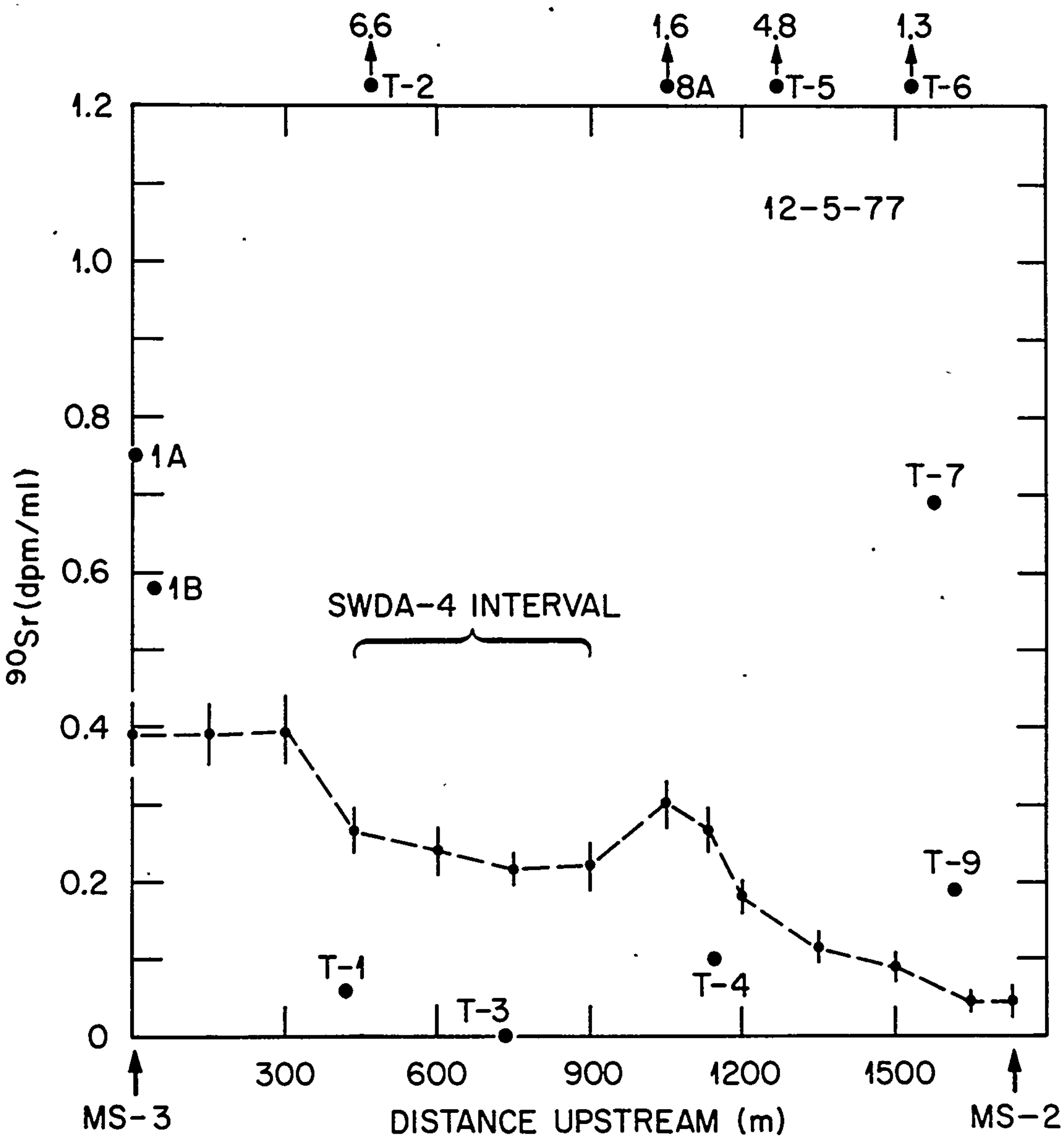


Fig. A-2. Longitudinal profile of $^{90}Sr$ activity in White Oak Creek, December 5, 1977.

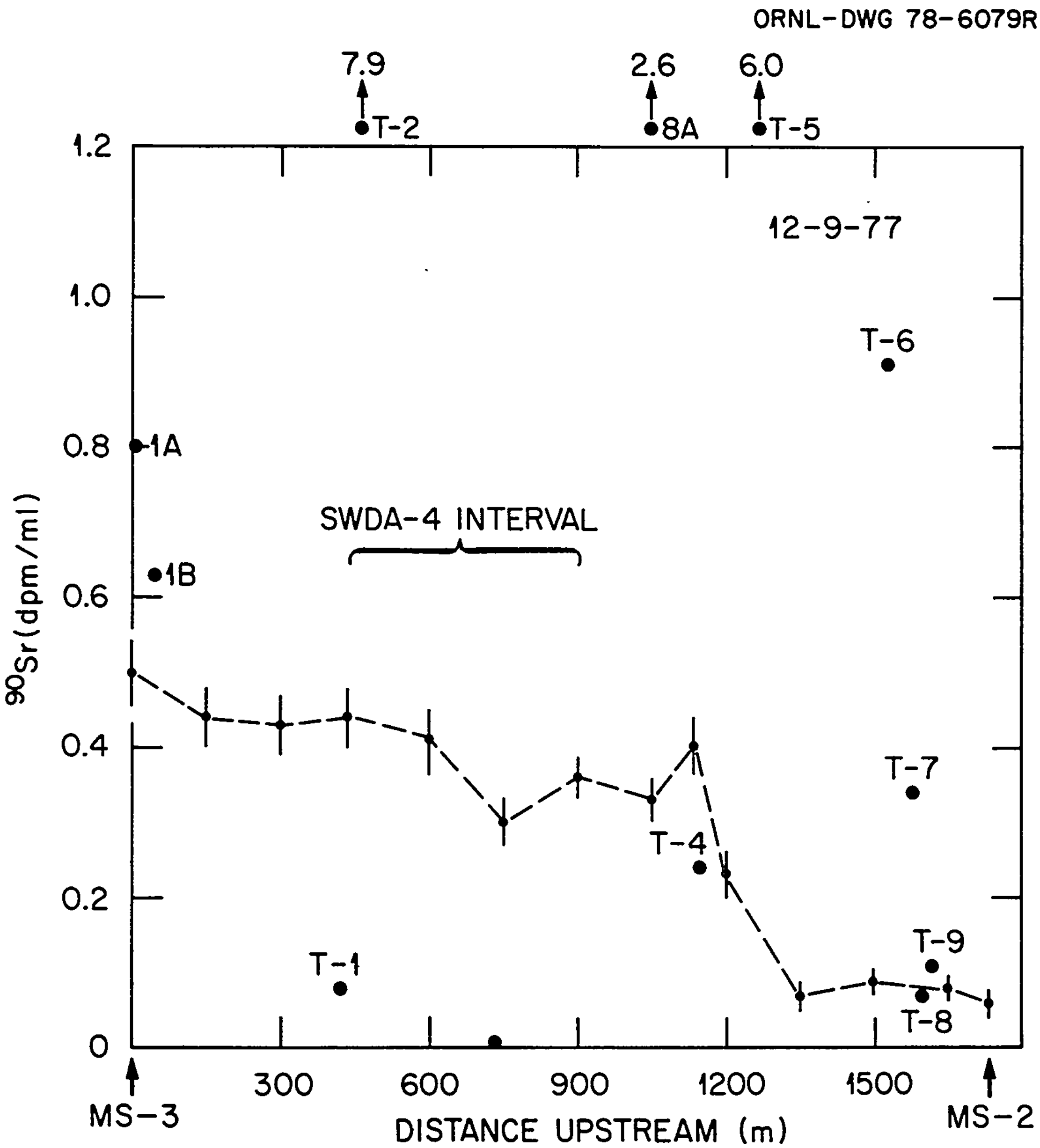


Fig. A-3. Longitudinal profile of $^{90}$Sr activity in White Oak Creek, December 9, 1977.

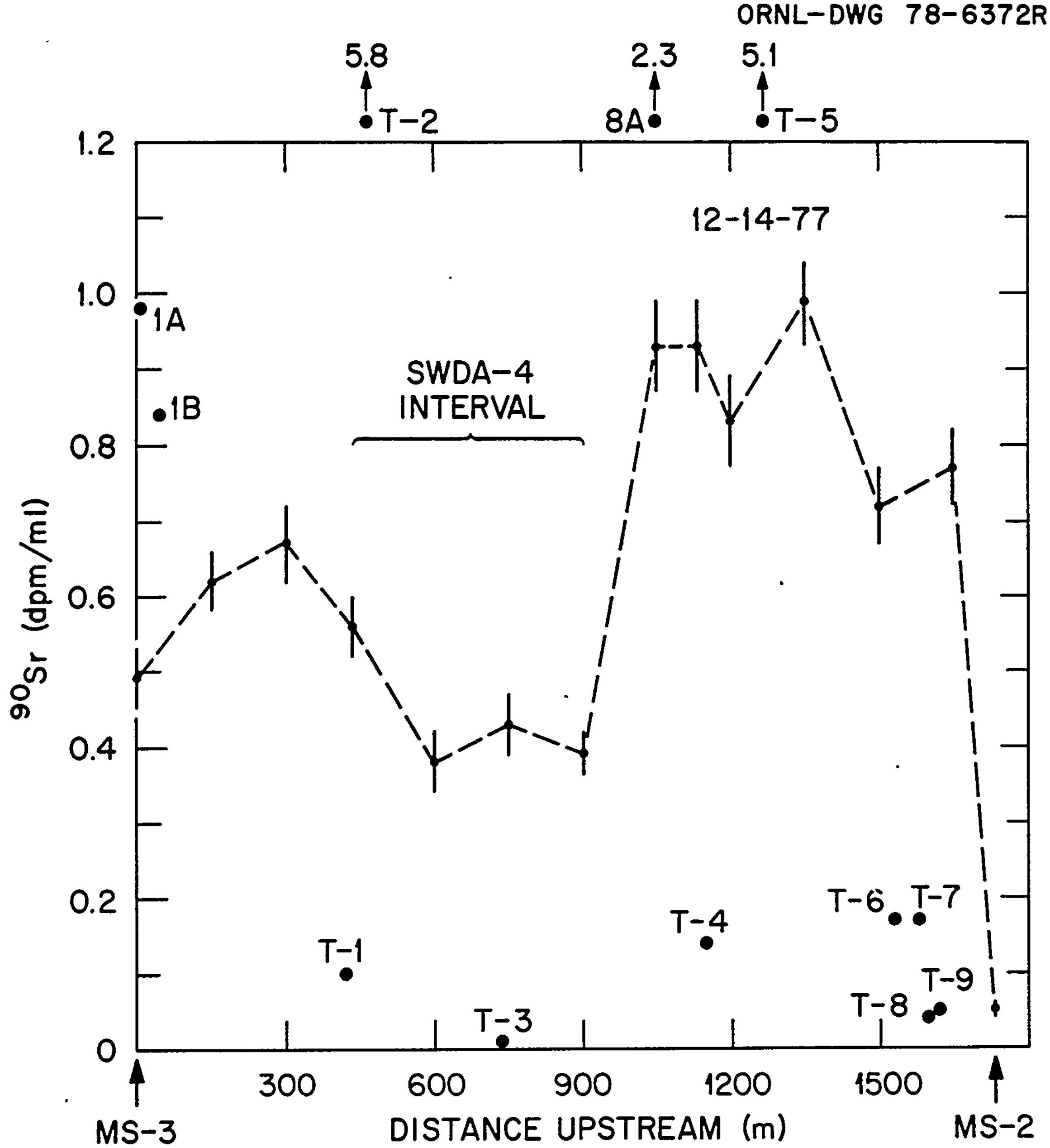


Fig. A-4. Longitudinal profile of $^{90}$Sr activity in White Oak Creek, December 14, 1977.

ORNL-DWG 78-6078R

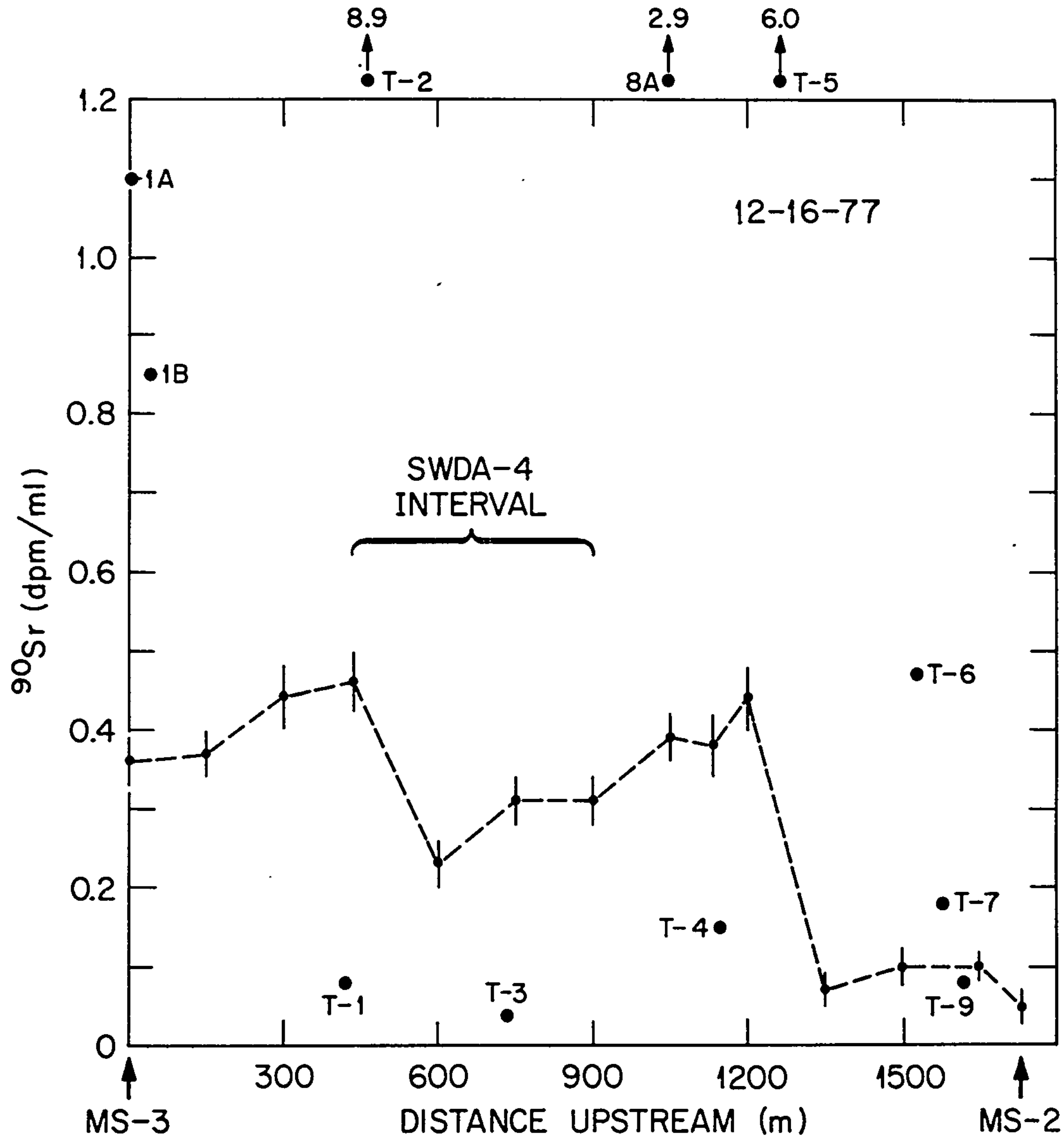


Fig. A-5. Longitudinal profile of $^{90}$Sr activity in White Oak Creek, December 16, 1977.

ORNL-DWG 78-6077R

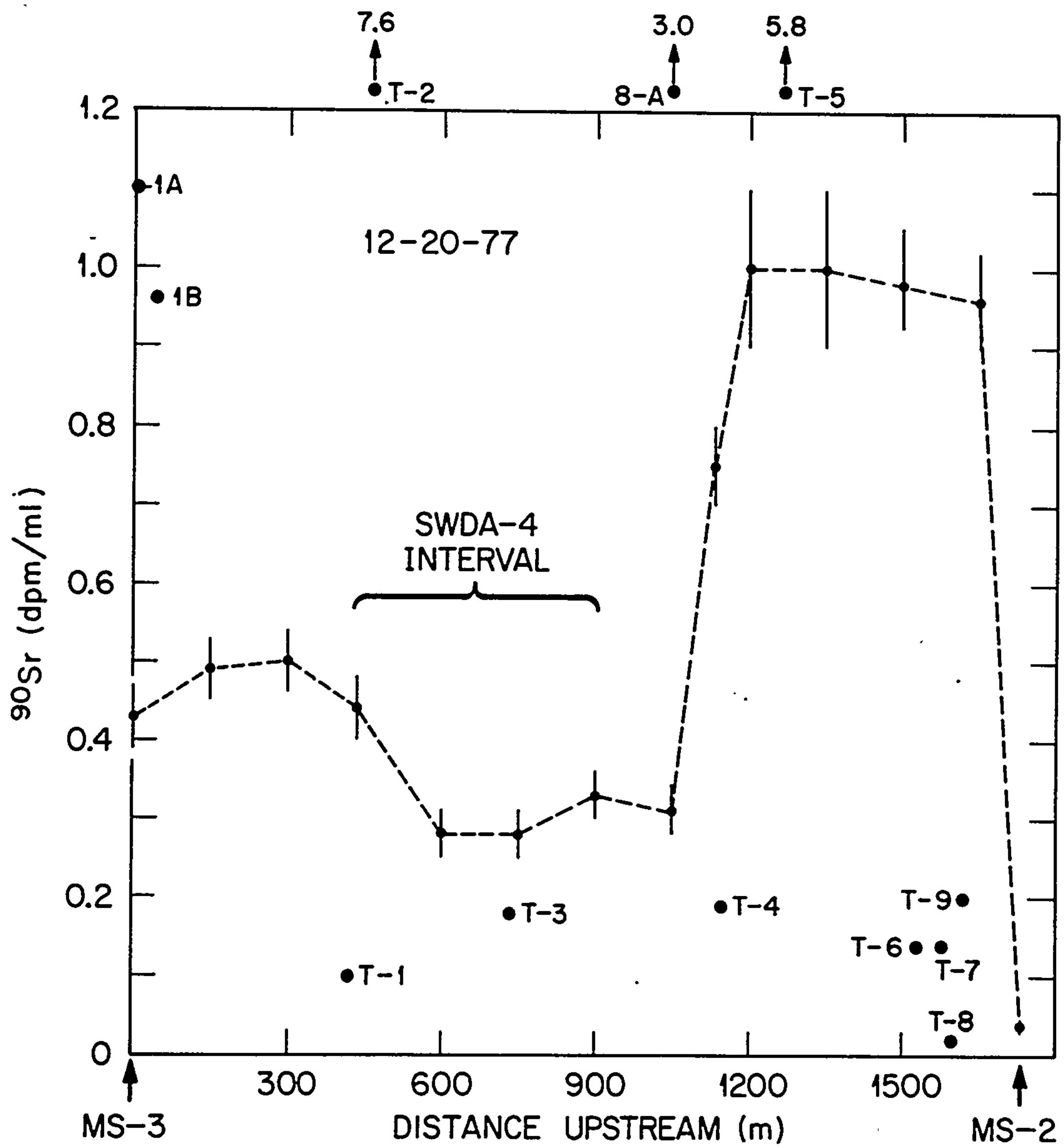


Fig. A-6. Longitudinal profile of $^{90}$Sr activity in White Oak Creek, December 20, 1977.

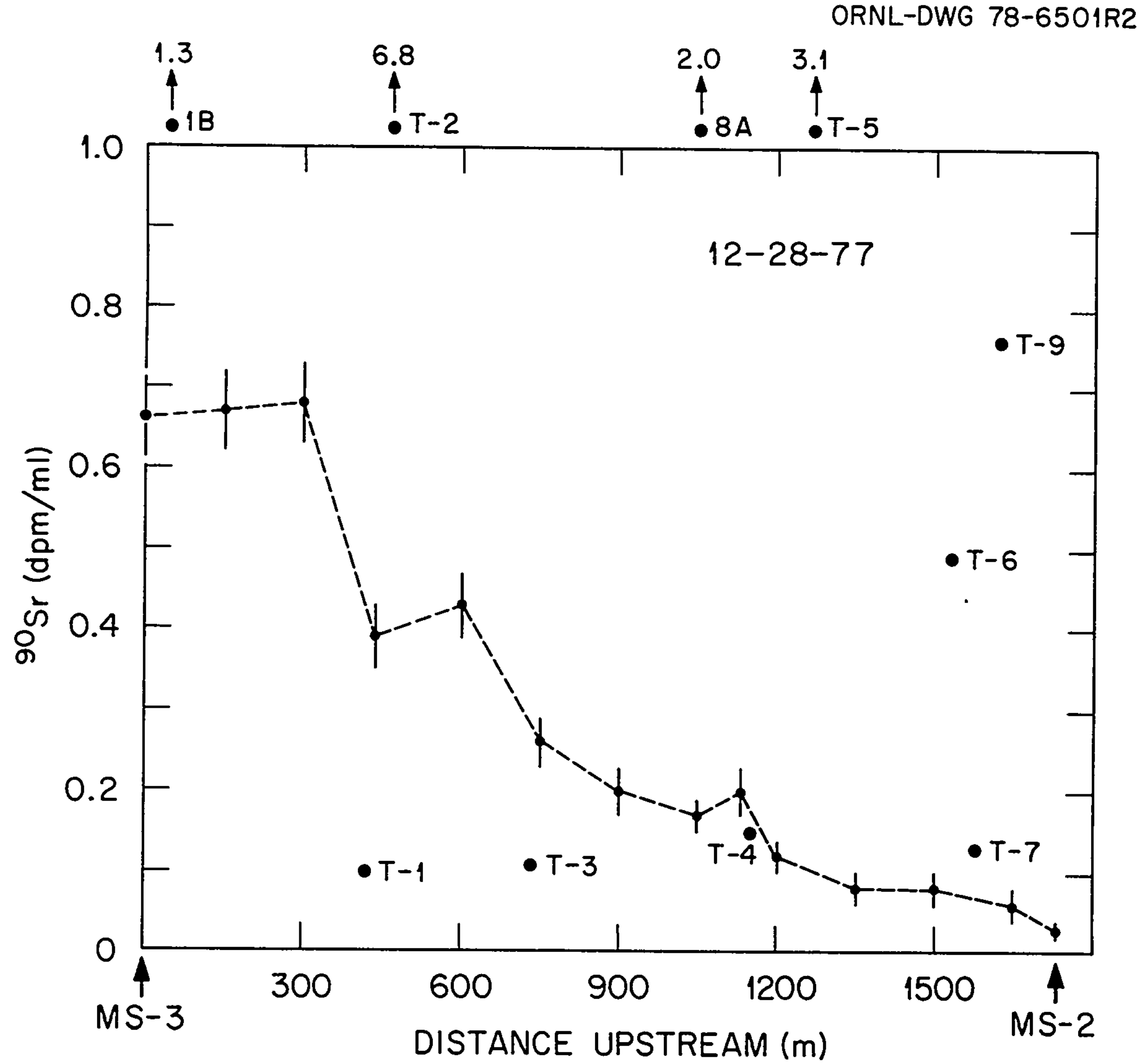


Fig. A-7. Longitudinal profile of $^{90}$Sr activity in White Oak Creek, December 28, 1977.

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